이학박사학위논문

Responses by phytoplankton communities to temperature elevation in the vicinity of condenser effluent from nuclear power plants and mixotrophic ecology of a newly described dinoflagellate species, *Ansanella granifera*

원전 온배수 영향 해역 수온 상승에 대한 식물플랑크톤 군집의 반응 및 신규 기재 와편모류 종인 *Ansanella granifera*의 혼합영양 생태 연구

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Abstract

Responses by phytoplankton communities to temperature elevation in the vicinity of condenser effluent from nuclear power plants and mixotrophic ecology of a newly described dinoflagellate species, *Ansanella granifera*

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The effect of future global warming and climate change on marine ecosystems could be estimated by the ecosystem change in the waters adjacent to the thermal condenser effluent from nuclear power plants. As of the end of 2014, there are 437 nuclear power plants in operation around the world. In Korea, there are 24 units in operation and the temperature rise(△T) across the condenser is about 7~9 ℃.

The effect of warming on phytoplankton communities was analyzed based on data collected from 9 sampling stations in the Hanbit and Hanul nuclear power plant sites where field cruises were carried out seasonally for 11 years since 1999.

To predict the effect of global warming and temperature rise of seawater on marine ecosystems, (1) physicochemical properties of seawater near nuclear power plants were determined, and abundance and biomass of phytoplankton were analyzed. Furthermore, (2) seasonal data were analyzed with respect to temperature rise. (3) Based on the seawater properties and phytoplankton communities, effects of the temperature rise on marine ecosystems were predicted.

Between 1999 to 2009, temperature varied from 2.4 to 37.6℃ in Hanbit site and from 7.8 to 30.2℃ in Hanul site. The Hanbit and Hanul sites showed notable differences in physicochemical properties such as nutrient concentrations, water transparency, and tidal current velocity as well as biological properties such as the composition of dominant phytoplankton groups.

The peaks of diatom biomass were observed at 11℃ and 32℃ for Hanbit, but 4℃ and 20℃ for Hanul. However, peaks for dinoflagellate were observed at higher temperatures than diatom with peaks at 14℃, 29℃ and 35℃ for Hanbit. For Hanul, the biomass of dinoflagellate increased from 14℃ to 20℃ and decreased above 20℃.

The peaks of net-phytoplankton expressed as chlorophyll *a* concentration were observed at 11℃ and 26-29℃ at both Hanbit and Hanul. At temperatures where the abundances of total phytoplankton were high, the chlorophyll *a* of net-phytoplankton was the dominant fraction. However, at low temperatures or very high temperatures (above 35℃ in Hanbit), chlorophyll *a* of nano-phytoplankton was the dominant fraction.

The effect of temperature elevation on the phytoplankton abundance was not always negative. Generally, the phytoplankton abundances at the discharge station was lower than those at intake station. However, in winter, thermal condenser effluent from Hanbit resulted in increased phytoplankton abundances at the discharge station (i.e., positive effect). The water temperature at the Hanbit discharge station varied from 3.3~18.8℃.

Base on the changes in dominant phytoplankton groups associated with increasing water temperature, it is expected that a temperature increase due to global warming may cause increases in the fraction of dinoflagellates relative to the other phytoplankton. Furthermore, dominance by eurythermal and high-temperature adapted planktons is expected.

Thus, present results may provide a basis to better understanding of the effects of thermal discharge effluent on marine ecosystems, especially on abundance and biomass of phytoplankton and predicting changes in marine phytoplankton community due to global warming.

As the one of most remarkable indicators for the rise of seawater temperature, the ratio of dinoflagellates to total phytoplankton was shown to be very important in this study. Thus, revealing the eco-physiological responses of dinoflagellates, in particular new species, to different temperatures is very important.

I explored the growth-associated eco-physiology of a newly described mixotrophic dinoflagellate *Ansanella granifera* isolated from the water of Shiwha Bay, Korea in 2010. I explored the feeding mechanism and the different types of species that *A. granifera* was able to feed on. In addition, I measured the growth and ingestion rates of *A. granifera* feeding on the prasinophyte *Pyramimonas* sp., the only algal prey, as a function of prey concentration. *A. granifera* was able to feed on heterotrophic bacteria and the cyanobacterium *Synechococcus* sp. However, among the 12 species of algal prey offered, *A. granifera* ingested only *Pyramimonas* sp. *A. granifera* ingested the algal prey cell by engulfment. With increasing mean prey concentration, the growth rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but became saturated at a concentration of 434 ng C mL^{-1} (10,845 cells mL^{-1}). The maximum specific growth rate (i.e., mixotrophic growth) of *A. granifera* feeding on *Pyramimonas* sp. was 1.426 d^{-1}, at 20°C under a 14 : 10 h light-dark cycle of 20 µE m^{-2} s^{-1}, while the growth rate (i.e., phototrophic growth) under similar light conditions without added prey was 0.391 d^{-1}. With increasing mean prey concentration, the ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but slightly at the concentrations $\geq$306 ng C mL^{-1} (7,649 cells mL^{-1}). The maximum ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. was 0.97 ng C $predator^{-1}$ d^{-1} (24.3 cells $grazer^{-1}$ d^{-1}). The calculated grazing coefficients for *A. granifera* feeding on co-occurring *Pyramimonas* sp. were up to 2.78 d^{-1}. The results of the present study suggest that *A. granifera* can sometimes have a considerable grazing impact on the population of *Pyramimonas* spp. Present results on *A. granifera* may provide a firm basis for the understanding of eco-physiological characteristics of the mixotrophic dinoflagellates and their roles in marine planktonic food webs in marine ecosystems.

Results from this study may be applied to predict the changes in marine phytoplankton community by global warming in the ocean as well as at the coastal waters near nuclear power plants.

Key Words: engulfment; feeding; growth; ingestion; mixotrophy; nuclear power plant; phytoplankton; thermal condenser effluent

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Chapter 1. Introduction

As a result of global warming and climate change, the temperatures of atmosphere and ocean around the world continue to increase. According to IPCC report published in 2014, increase of global mean surface temperatures for 2081-2100 relative to 1986-2005 is 0.3 to 4.8℃ depending on the climate scenario. Best estimates of ocean warming in the top one hundred meters are about 0.6 to 2.0℃ by the end of the 21st century(IPCC AR5, 2014).

Marine phytoplankton are known to play important roles as primary producers. Survival of dominant species is the most important thing in maintaining the stability of a marine food web. Each phytoplankton species has optimal and tolerable water temperature range. Thus, elevation of the water temperature may change the phytoplankton communities.

The thermal discharge effluent from nuclear power plants can affect the coastal ecosystem around the nuclear power plants(hereafter NPPs). This provides a good opportunity to study the effect of temperature elevation on the marine ecosystem.

At the end of 2014, there are 437 operable nuclear power reactors around the world, with electric generation capacity of 377,322 MWe. In 2014, they generated 2,359 billion kWh of electricity(WNA 2015). There are 24 nuclear power plants operated commercially in Korea as of October 2015. The installed capacity of these power plants are 21,716 MWe, which holds 30% of total electric power generation in Korea. Moreover 4 additional nuclear power plants are under construction with 4 more units planned for future construction.

The Korea Hydro & Nuclear Power Co. Ltd.(hereafter KHNP) has issued the 10^{th} and 15^{th} commemorative comprehensive reports on the environmental survey in the areas around the NPP complexes, but these reports lack the analyses of detailed data due to focusing on the average value analysis at the whole stations. There has been no study on the concentrated analysis of phytoplankton community change more than 10 years around the NPP complex area in Korea.

In this study, the relationship between phytoplankton community and increase in water temperature is analyzed based on data collected near nuclear power plants over 11 year period from 1999 to 2009. By studying the effect of warm water discharge to near by marine ecosystem, a better assessment of the effect of future global warming and climate change on marine ecosystem can be made.

The abundance of Bacillariophyceae is the main contributing factor to the abundance of total phytoplankton. The Bacillariophyceae dominated phytoplankton and the next dominant taxon was Dinophyceae in Hanbit and Hanul area. Phototrophic dinoflagellates are one of the major components in marine planktonic communities (Smayda 1997, Jeong et al. 2013a, 2013b, Park et al. 2013a). In autumn of 2010, a new mixotrophic dinoflagellate *Ansanella granifera* was found in Shiwha Bay, Korea (Jeong et al. 2014a). Although the habitat for this species is not well established, this species can be found near nuclear power plants in the future. I established a clonal culture of *A. granifera* and observed its feeding behavior under high-resolution video-microscopy in order to explore the feeding mechanisms and determine the prey species when diverse algal species were provided. I also conducted experiments to determine the effects of prey concentration on the growth and ingestion rates of *A. granifera* feeding on the prasinophyte *Pyramimonas* sp., the only algal prey, as a function of prey concentration. In addition, I estimated the grazing coefficients attributable to *A. granifera* feeding on *Pyramimonas* sp. using the ingestion rate obtained from the laboratory experiments and the abundances of predators and prey in the field. The observation of feeding method and feeding rate of new species through culture experiments can help better understand changes in the phytoplankton community near nuclear power plants.

Chapter 2. Responses by phytoplankton communities to temperature elevation in the vicinity of condenser effluent from nuclear power plants

2-1. Introduction

The overall efficiency of operating nuclear power plants falls between 32% and 33% during 2002 through 2012 (EIA-923/EIA-860, 2013) and all the nuclear power plants need huge amount of cooling water for the cooling of their condensers. This cooling water comes mainly from the river or the sea, and all the nuclear power plants in Korea use seawater as their condenser cooling water. That’s the reason why all the nuclear power plants in Korea are located at the coast. The thermal discharge effluent to the sea after cooling the condensers can affect the coastal ecosystem adjacent to the nuclear power plants (Naylor, 1965; Blake et al., 1976; Langford, 1990).

Coastal power plants using sea water for cooling can affect marine life from collision with intake facility, thermal stresses experience by micro-organisms entrained, and changes in community structure near by area due to rise in water temperature (Barnett, 1973; Langford, 1990).

The temperature difference between intake and discharge seawater is designed to be about 7～9 ℃ in Hanbit and Hanul nuclear power plants. The flow rate of the condenser discharge water ranges about 40 to 50 m^3 $unit^{-1}$ sec^{-1}. The flow rates of the thermal discharge effluent are 337.2 m^3 sec^{-1} and 318.2 m^3 sec^{-1} in Hanbit nuclear power plant complex and in Hanul nuclear power plant complex, respectively, which show similar value. Since the nuclear power plant sites located at East Sea and West Sea in Korea have same capacity of electric generation, at this moment, the examination and verification of the medium term effect on marine environment caused by the thermal discharge effluent in relation to the marine characteristics on these two different seas will be meaningful.

The influence of thermal discharge on marine environment is not clear. Some studies have identified reductions in microbial biomass, primary production, and zooplankton biomass up to 200 m from the outlet. In contrast, other studies have found no detectable effects of cooling water discharge upon plankton community beyond the actual discharge outlet (Lo *et al*, 2004). Moreover, increased seawater temperature by thermal discharge contribute to the phytoplankton growth (Ilus and Keskitalo 2008).

Many studies on marine ecosystem near nuclear power plants were performed in other countries (Barnett, 1972; Briand, 1975; Eppley, 1972, Langford, 1990), as well as in Korea (Kim, 1983; Lee, 1987; Shim *et al*., 1991; Kim *et al*., 1985; Yeo and Shim, 1992; Kang 2001; Kang *et al*. 2001; Kang *et al*. 2002). And also there were studies on the phytoplankton community behaviour in the sea area of Chooksan harbor near Hanul nuclear power plant complex (Kang *et al*., 2005) and on the phytoplankton community characteristics in the near sea around power plants (Kang, 2008).

To predict global warming by oceanic temperature rise, (1) Physicochemical properties of ocean near nuclear power plants were identified, and biomass and phytoplankton abundance were analyzed. (2) Seasonal raw data were analyzed by plotting with respect to temperature rise.

(3) Based on the results, predictions were made for future global warming trend. To answer these questions, 2 power plant site (Hanbit nuclear power plants in Yonggwang on the west coast, Hanul nuclear power plants in Ulchin on the east coast) with similar thermal discharge effluent rates were selected, and for each site, 9 stations (intake, discharge, reference, R1, R2, C1, C2, L1 and L2 stations) were selected. From these selected stations, data on physicochemical properties, and characteristics of phytoplankton community were collected and analyzed. Both abundance and biomass data for phytoplankton were collected and analyzed. To find relationship between various parameters, physicochemical properties were correlated with biological properties.

Environmental changes due to nuclear power plant operation are likely to occur over long period of time and continuous and long term monitoring and analysis are required.

2-2. Materials and methods

Study sites and sampling dates

Fig. 2-1 is the sampling station maps of Hanbit and Hanul nuclear power plants. The Hanbit site is located at 35°22′04″ ~ 35°28′28″N latitude and 126°21′50″ ~ 126°26′30″E longitude (Fig. 2-1 (a)). Neighboring coast is shallow and sediment compositions are mostly clayey silt or silty clay(KEPCO, 2000). Near Hanbit area are semidiurnal tide with flood and ebb currents occurring twice per day. The West sea has larger tidal range than East sea. The average current velocity around Hanbit NPP site ranges from 10~30 cm sec^{-1} and maximum velocity ranges from 40~70 cm sec^{-1}.

The Hanul site is located at 37°04′00″ ~ 37°07′09″N latitude and 129°23′04″ ~ 129°26′00″E longitude (Fig. 2-1 (b)). The sediment compositions are sand with low mud content(KEPCO, 2000). Near Hanul area are semidiurnal tide with flood and ebb currents occurring twice per day. In Hanul NPP site, average current velocity ranges from 5~15 cm sec^{-1} and maximum velocity ranges from 15~20 cm sec^{-1}.

The electric generation capacity of Hanbit complex is the same as the Hanul complex's capacity, 5,900 MWe. Each complex discharges through a single water channel and the amount of thermal discharge effluent were 337.2 m^3 sec^{-1} for Hanbit complex and 318.2 m^3 sec^{-1} for Hanul complex.

Meanwhile, now on Hanul site the Shin-Hanul NPP unit 1 & 2 are under construction and planned to start commercial operation in February 2018, and Shin-Hanul NPP unit 3 & 4 are preparing for their construction which will be operated commercially in 2021 and 2022 respectively. Each of these 4 units of Shin-Hanul NPPs has a capacity of 1,400 MWe which is 400 MWe greater than that of previous NPPs on the same site. Therefore, the total capacity in the Hanul NPP complex will be 11,500 MWe by 2022.

In Hanbit NPP sites the warm discharge from the 6 units flows together through a single water channel to the western coast of Korea. The water channel's upper width is about 80 m, bottom width about 15 m, and its total length is around 2 km. The channel's depth lies between (-)11 to (+)9.5 on M.S.L(Mean Sea Level) basis and it has trapezoidal shape cross section with flat bottom. The water channel in Hanul NPP has almost the same configuration as Hanbit NPP. But Shin-Hanul NPPs will have different type of discharge water channel which has intake and discharge into the sea far away from the coast to diminish the thermal effect on marine environment.

The unit specific electric capacity and warm discharge water flow rate of each unit in Hanbit and Hanul NPP sites are shown in Table 2-1. The condenser △T of Hanbit and Hanul NPPs are designed to be from 7 to 9 ℃. For Hanbit NPP on the west coast, the average temperature rise in the discharge station are 6~7.5 ℃. For Hanul NPP on the east coast, the average temperature rise in the discharge station are 3.5~5.5 ℃.

The number of sampling stations increased in recent years, but to maintain consistency during the entire 11 year period, only the data from 9 stations were used in the analysis. The 9 stations used in analysis are intake, discharge, reference station, right side of discharge(R1, R2), left side of discharge(L1, L2), and center of discharge(C1, C2).

Discharge station is most important station since comparison of physical, chemical and biological characteristics of discharge with those of reference station should clearly show the effect of power plant operation on marine environment and ecosystem.

The intake station is not far from the discharge, but the intake station show the characteristics of marine ecology just before being exposed to thermal effect of the power plant. By comparing species composition and abundance at intake and discharge stations, the effect of water temperature rise due condenser heat dissipation can be analyzed.

Quarterly survey was made to examine the seasonal variations among winter, spring, summer and autumn. The phytoplankton sampling dates during the environmental examination from 1999 to 2009 are summarized in Table 2-2.

(a)

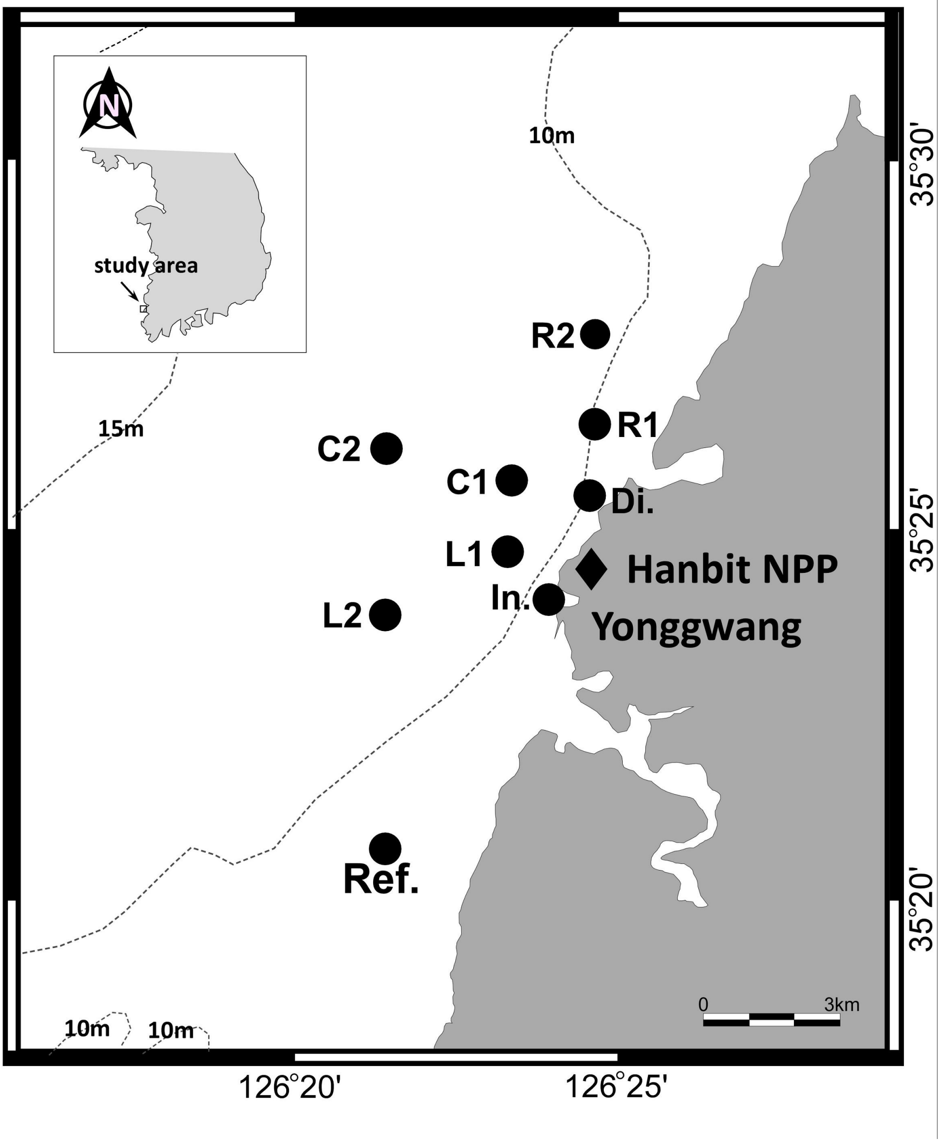


Fig. 2-1. Sampling station maps (a) Hanbit nuclear power plants site

(b)

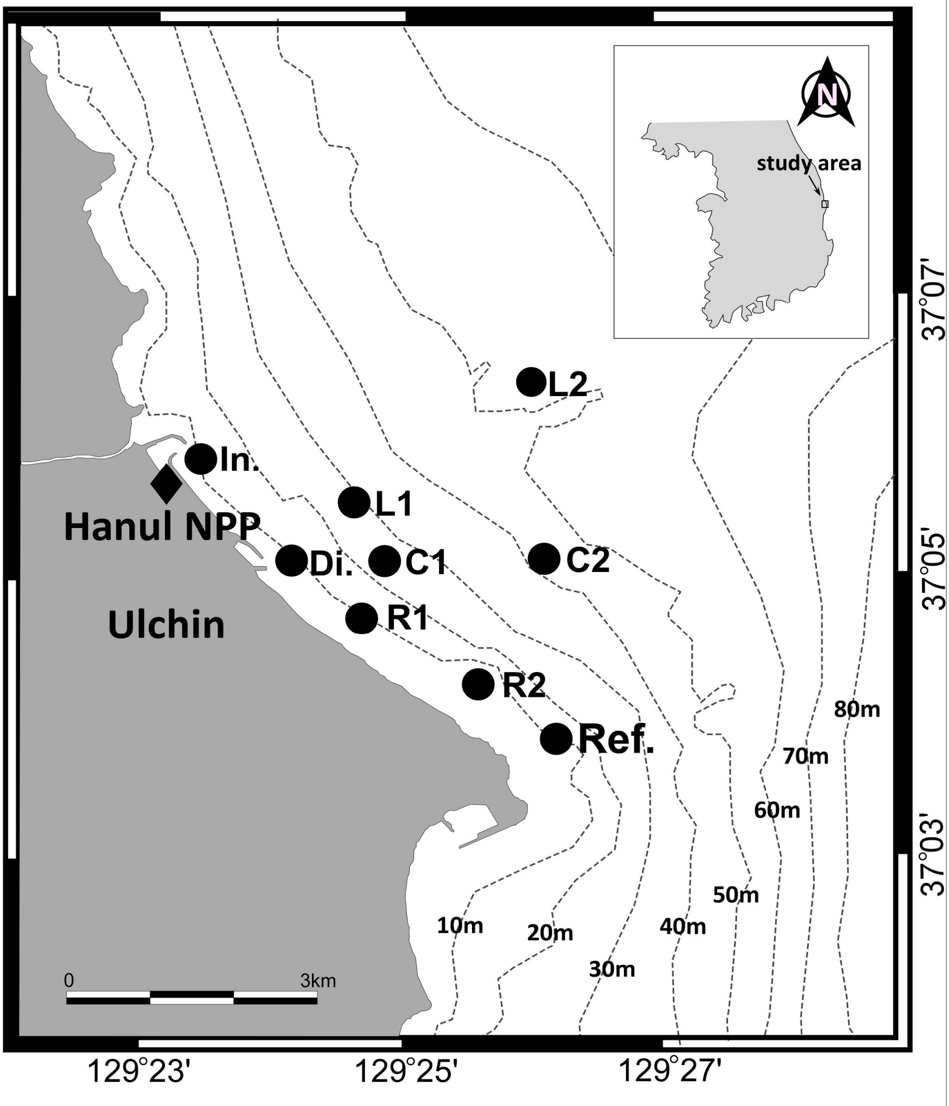


Fig. 2-1(cont.). Sampling station maps (b) Hanul nuclear power plants site

Table 2-1. Generation capacity, thermal discharge effluent flow rate and designed condenser △T of each unit in Hanbit and Hanul sites (quoted from KHNP data)

unit (capacity : MWe)		Amount of cooling water (m^3 sec^{-1})	condenser △T (℃)
Hanbit	#1(950)	54.1	8.7
	#2(950)	54.1	8.7
	#3(1,000)	49.7	8.8
	#4(1,000)	49.7	8.8
	#5(1,000)	64.8	6.9
	#6(1,000)	64.8	6.9
sum	5,900	337.2	-
Hanul	#1(950)	59.7	7.3
	#2(950)	59.7	7.3
	#3(1,000)	49.7	9.0
	#4(1,000)	49.7	9.0
	#5(1,000)	49.7	9.0
	#6(1,000)	49.7	9.0
sum	5,900	318.2	-

Table 2-2. Phytoplankton sampling date (1999～2009) (quoted from KHNP data)

year	winter		spring		summer		autumn	
	Hanbit	Hanul	Hanbit	Hanul	Hanbit	Hanul	Hanbit	Hanul
1999	2.4	2.9	4.20	5.11	8.17	8.5	11.9	11.2
2000	2.7	2.22	5.3	4.25	8.1	7.25	10.31	10.24
2001	2.6	2.13	4.24	5.9	8.7	8.1	11.7	11.7
2002	2.5	1.31	4.18	4.23	7.23	8.6	11.5	10.29
2003	1.15	1.21	4.15	4.22	7.15	7.22	10.21	10.7
2004	2.10	2.4	4.13	4.3	7.22	8.4	11.4	10.2
2005	2.3	2.15	4.12	4.19	8.2	7.12	11.1	10.27
2006	2.15	2.9	5.7	5.18	8.17	8.1	11.16	10.26
2007	3.19	2.6	5.7	5.3	8.7	7.19	11.5	11.14
2008	2.19	1.29	5.13	4.22	8.12	7.29	11.10	10.21
2009	2.2	3.16	5.9	5.11	8.21	8.11	10.21	10.26

Physicochemical factors

Water samples were taken at each station with van-Dorn water samplers quarterly from February 1999 to November 2009. All parameters were reviewed to investigate surface water quality. Data which can be measured on site such as temperature, pH, dissolved oxygen, residual choline were recorded on site. For general analysis and measurement of nutrients, samples of water were taken in cleaned 2L polyethylene bottle and refrigerated during transport to the lab. For analysis of heavy metal, samples were taken in 1L Teflon bottles cleaned with acid and transported to the laboratory for analysis. Measurement & analysis were carried out according to 「the Official Test Methods for Water Pollution of ROK」 or 「the Standard Methods for the Examination of Water and Wastewater(Ministry of land, transport and maritime affairs 2010)」.

The examined parameters were temperature, salinity, transparency, suspended solids(SS), DO, pH, COD, NO_2, NO_3, NH_4, total-N, PO_4, and SiO_2. Analytical methods used to measure water quality are in table 2-3.

Table 2-3. Analytical methods used to measure surface water quality parameters (quoted from KHNP data)

parameter	analytical method
Temperature	Electrometric method
Salinity	Electrical conductivity method
Transparency	Secchi depth measurement
PH	Electrometric method
Electrical Conductivity	Electrometric method
Turbidity	Nephelometric method
DO	Membrane electrode method
COD	Titration method($KMnO_4$)
TS, SS, TDS	Filter method
NH_3	Ion electrode method
NO_2, NO_3	Ion chromatographic method
T-N, PO_4	Absorption spectrometric method

Biological factors

Phytoplankton surveys were conducted in the areas of Hanbit and Hanul nuclear power plants and samples were collected in winter, spring, summer and autumn from February 1999 to November 2009.

For the identification of phytoplankton, samples were collected using a Kitahara-type - 60µm(before 2006), 40µm(2006~2008) and 20µm(after 2009) - net by hauling it vertically and preserved with formalin in 250-mL polyethylene bottle (UNESCO, 1978). Samplers for the quantitative analysis were collected with a Van-dorn or Niskin sampler from each stations. Samples were collected in 500-mL polyethylene bottles and preserved with Lugol's solution in darkness (UNESCO, 1978). Phytoplankton cell enumeration was performed with a Sedgwick-Rafter counting chamber under a light microscope. The chlorophyll *a* concentrations were measured by acetone extraction method and measured by fluorometer.

To measure concentration of chlorophyll *a*, 250～500㎖ of water samples were taken from near the surface and filtered with GF/C(Wheatman) filter on site. Then, filters were put in 20㎖ vial and refrigerated for transport to the laboratory. In the laboratory, chlorophyll *a* were extracted by acetone extraction method, where filter was placed in 10㎖ of 90% acetone and refrigerated for 24 hours. The chlorophyll *a* extract was filtered with 25mm GF/C to filter out suspended particles. The chlorophyll *a* extract was analyzed with Turner fluorometer (Turner Designs Model 10 & TD-700) and concentration was quantified using fluorometric method (Parsons et al., 1984).

The diversity of phytoplankton was calculated by Shannon-Wiever Diversity Index.

$$H' = -\sum_{i=1}^{s} P_i \ln P_i \qquad (1)$$

Pi : ni/N,

s : species nunber,

N : total abundance

ni : abundance of ith species

To quantify the effect of growth inhibition, growth inhibition ratio, defined as change in concentration of chlorophyll *a* at the intake and discharge of the cooling water system, normalized to concentration at the intake was used as shown in equation below.

$$GI(\%) = \frac{Chl_{In} - Chl_{Dis}}{Chl_{In}} \times 100 \qquad (2)$$

GI : Growth inhibition

Chl_{In} : Concentration of chlorophyll *a* at intake

Chl_{Dis} : Concentration of chlorophyll *a* at discharge

Statistical analysis

Four seasonal data from intake, discharge, reference, C1, C2, R1, R2, L1 and L2 station of Hanbit and Hanul nuclear power plants from 1999 to 2009 were used to assess the effect of natural variability in temperature and nutrients on phytoplankton community.

The following data are missing due to equipment failure or not included as sampling station at the time : In case of Hanbit, temperature, pH, DO for autumn of 1999 and SiO_2 for winter, spring and summer of 2008, are missing. In case of Hanul, temperature for spring of 1999 and transparency for autumn of 1999 and chlorophyll *a* for summer of 2005, are missing. And all physical and chemical data of L1 station for autumn of 1999 and C2 station for winter of 2001 are missing.

The correlation coefficients between phytoplankton and physical, chemical and biological properties were calculated using the Pearson’s correlation of SPSS statistics package (Conover, 1980; Zar, 1999).

2-3. Results

2-3-1. Characteristics of Hanbit site

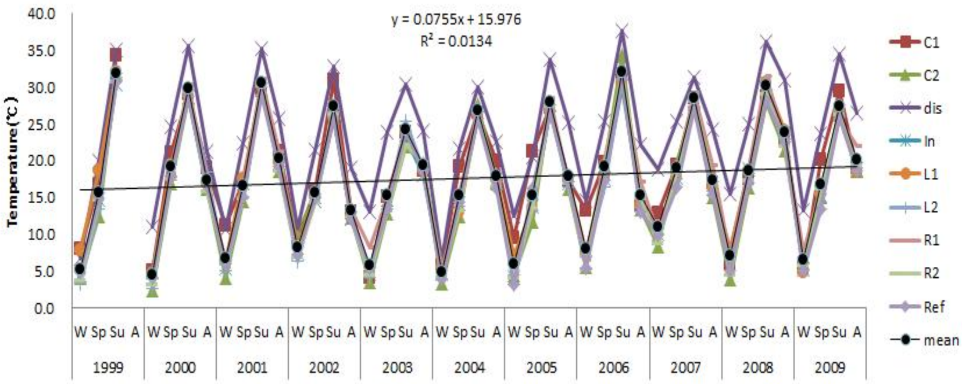
Physicochemical properties

The physicochemical properties were collected at 9 station in Hanbit site over a period of 11 years starting from 1999. Between 1999 to 2009, temperature varied from 2.4 to 37.6℃, transparency varied from 0.1 to 19.8 m, pH varied from 7.68 to 8.42, Dissolved oxygen(DO) varied from 4.8 to 15.9 mg L^{-1}, chemical oxygen demands(COD) varied from 0.5 to 8.1 mg L^{-1}, suspended solid(SS) varied from 2.0 to 107.6 mg L^{-1}(Fig. 2-2).

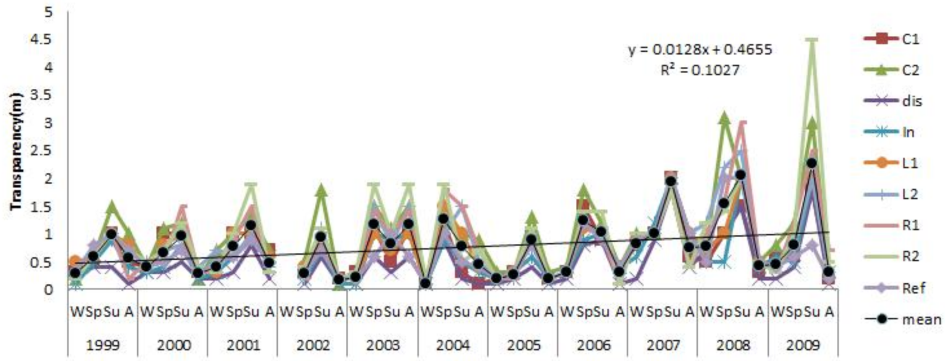
Based on the results of physicochemical analysis of Hanbit area, the seasonal variations were larger than annual variations during 11 years of observation. Over the 11 years, the temperature and transparency showed slight increase. The SS and COD increased slightly for Hanbit area. The DO decreased slightly and this was related to the increase of temperature.

The pH was determined by the ratio of carbonate and bicarbonate ions. The seasonal variations of pH are shown in Fig. 2-2 (c). And through the entire observation period, the pH remained within 7.87 - 8.05 which meets the class 1 water quality standards set by the Korea Mistry of Environment. Ocean acidification is quantified by decreases in pH. During the observation period, some seasonal or annual variations in pH were found, but no significant changes were found that would indicate midium term ocean acidification around Hanbit sites. But the magnitude of pH variation was increasing for Hanbit site for 2008~2009 and further monitoring is needed.

(a)



(b)



(c)

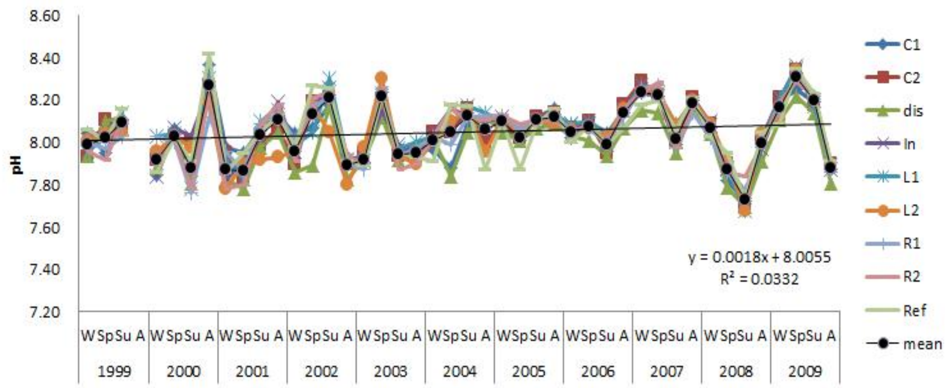
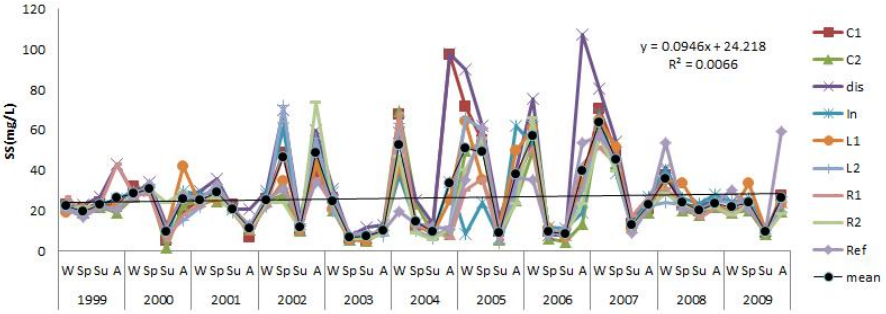
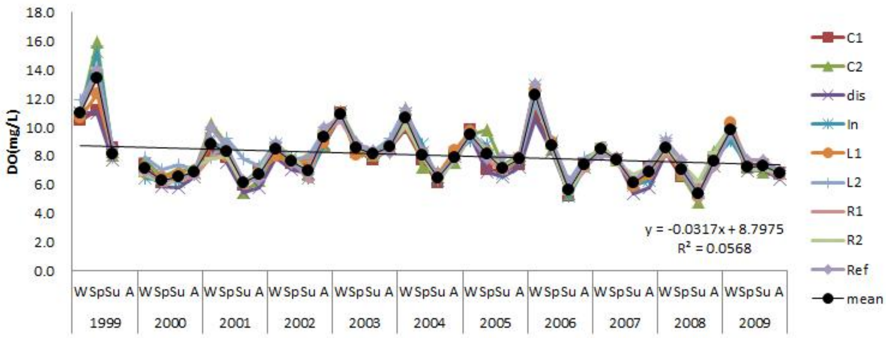


Fig. 2-2. Annual, seasonal variation of physicochemical properties in Hanbit NPP area (a) Temperature(℃), (b) Transparency(m) and (c) pH (quoted from KHNP raw data)

(d)



(e)



(f)

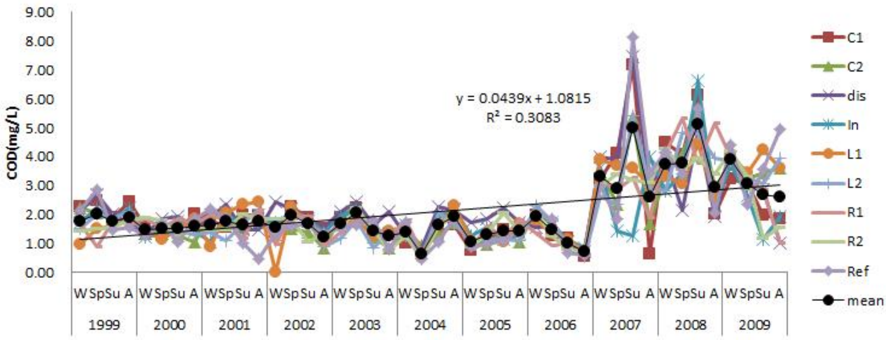


Fig. 2-2(cont.). Annual, seasonal variation of physicochemical properties in Hanbit NPP areas (d) SS(mg L^{-1}), (e) DO(mg L^{-1}) and (f) COD(mg L^{-1}) (quoted from KHNP raw data)

Seasonal/annual variation in abundance and biomass of phytoplankton

Seasonal/annual variation in abundance and biomass of phytoplankton were compared at intake, discharge and reference stations. The biomass was calculated from abundance of each species and known carbon content of each species.

In Hanbit area, total phytoplankton's biomass and abundance ranged from 0.7 ng C mL^{-1} (1.6 cells mL^{-1}) to 924.7 ng C mL^{-1} (3,945.3 cells mL^{-1}). Bacillaiophyceae ranged from 0.3 ng C mL^{-1} (0.7 cells mL^{-1}) to 906.7 ng C mL^{-1} (3,940.1 cells mL^{-1}), Dinophyceae ranged from 0.1 ng C mL^{-1} (0.1 cells mL^{-1}) to 114.9 ng C mL^{-1} (200.8 cells mL^{-1}), Dictyochophyceae ranged from 0.1 ng C mL^{-1} (0.001 cells mL^{-1}) to 26.0 ng C mL^{-1} (47.4 cells mL^{-1}), Euglenophyceae ranged from 0.2 ng C mL^{-1} (0.001 cells mL^{-1}) to 25.4 ng C mL^{-1} (94.2 cells mL^{-1}), Cyanophyceae ranged from 0.004 ng C mL^{-1} (0.2 cells mL^{-1}) to 0.1 ng C mL^{-1} (6.3 cells mL^{-1}), Chlorophyceae ranged from 0.2 ng C mL^{-1} (0.1 cells mL^{-1}) to 3.9 ng C mL^{-1} (13.2 cells mL^{-1})(Table 2-4).

Appendix Table A-1 shows the maximum biomass and abundance of the top dominant species in Hanbit NPP from 1999 to 2009. This shows the effect of temperature on dominant species.

Table 2-4. The range of abundance and biomass of each phytoplankton group and the water temperature, pH, DO and SS in Hanbit area (quoted from KHNP raw data)

Taxa	T (℃)	pH	DO (mg L^{-1})	SS (mg L^{-1})	Abundance (cells mL^{-1})	Biomass (ng C mL^{-1})
Total phytoplankton	2.4-37.6	7.68-8.42	4.8-15.9	2.0-107.6	1.6-3,945.3	0.7-924.7
Bacillariophyceae	2.4-37.6	7.68-8.42	4.8-15.9	2.0-107.6	0.7-3,940.1	0.3-906.7
Dinophyceae	2.4-37.6	7.68-8.42	4.8-15.9	2.0-80.6	0.1-200.8	0.1-114.9
Dictyochophyceae	3.2-35.5	7.73-8.42	5.2-15.9	2.0-107.6	0.1-47.4	0.1-26.0
Euglenophyceae	2.7-35.5	7.78-8.26	5.5-14.1	5.0-72.0	0.1-94.2	0.2-25.4
Cyanophyceae	14.5-30.3	7.78-8.37	5.9-8.8	5.1-36.0	0.2-6.3	0.005-0.1

To avoid the detailed comparison error following the average treatment in the data analysis, 3 locations were selected: intake station before condenser, discharge station which is strongly affected by thermal condenser effluent and reference station which is not affected by thermal effluent. The data from these 3 stations have been intensively examined and analyzed for the medium term change of the phytoplankton communities to verify the effects on marine environment due to the thermal discharge effluent from the Hanbit NPP complexes.

In Hanbit, the intake station is located 1.5 km ahead of Hanbit nuclear power plant. The biomass and abundance of total phytoplankton during 1999 to 2009, ranged from minimum of 2.1 ng C mL^{-1} (4 cells mL^{-1}) to maximum of 873 ng C mL^{-1} (3,772 cells mL^{-1}). The discharge station is located 2 km north east of the intake station. The biomass and abundance of total phytoplankton during 1999 to 2009, ranged from minimum of 0.7 ng C mL^{-1} (1.6 cells mL^{-1}) to maximum of 625 ng C mL^{-1} (3,018 cells mL^{-1}). The reference station is located 10 km south west of Hanbit nuclear power plant. The biomass and abundance of total phytoplankton during 1999 to 2009, ranged from minimum of 0.94 ng C mL^{-1} (4 cells mL^{-1}) to maximum of 719 ng C mL^{-1} (3,809 cells mL^{-1})(Fig.2-3).

A large blooming of phytoplankton was observed in 2002. During winter and spring seasons, the dominant species were *Pararia sulcata* for intake and reference station and *Thalassiosira decipiens* for discharge station. During summer, the abundance of *Eucampia zodiacus* was more than 50% at all three stations. During autumn, the abundance of *Thalassiosira decipiens* was more than 60%

The Bacillariophyceae dominated phytoplankton and their biomass and abundance ranged from 1.6 ng C mL^{-1} (4 cells mL^{-1}) to 803 ng C mL^{-1} (3,772 cells mL^{-1}) in intake station, from 0.3 ng C mL^{-1} (0.7 cells mL^{-1}) to 582 ng C mL^{-1} (3,008 cells mL^{-1}) in discharge station and from 0.94 ng C mL^{-1} (4 cells mL^{-1}) to 712 ng C mL^{-1} (3,789 cells mL^{-1}) in refrence station. The abundance of Bacillariophyceae was the main contributing factor to the abundance of total phytoplankton(Fig.2-4).

From Fig. 2-3 and Fig. 2-4, I can see that the seasonal variation of total phytoplankton largely depends on the variation of Bacillariophyceae.

The next dominant taxon was Dinophyceae and their biomass and abundance during 1999 to 2009, ranged from minimum of 0.1 ng C mL^{-1} (0.1 cells mL^{-1}) to maximum of 78.1 ng C mL^{-1} (110 cells mL^{-1}) in intake station, ranged from minimum of 0 ng C mL^{-1} (0 cells mL^{-1}) to maximum of 106 ng C mL^{-1} (104 cells mL^{-1}) in discharge station, and ranged from minimum of 0 ng C mL^{-1} (0 cells mL^{-1}) to maximum of 100 ng C mL^{-1} (100 cells mL^{-1}) in reference station(Fig.2-5).

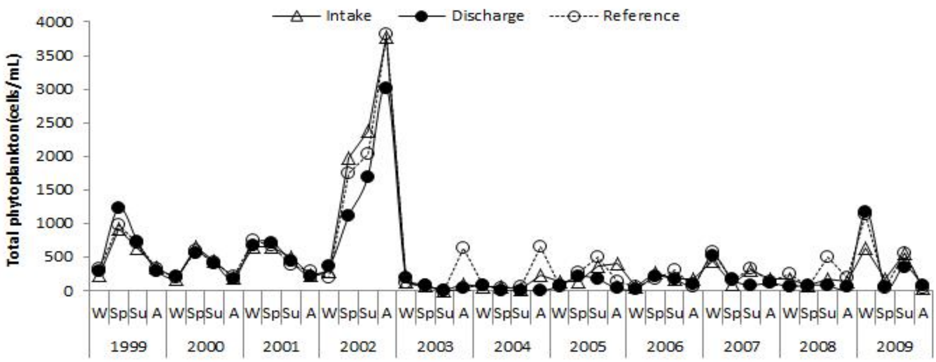
Although abundance and biomass of Dinophyceae were smaller than Bacillariophyceae with large blooming in 2002, the Dinophyceae showed more consistent trend in terms annual/seasonal variation. The dominant taxa of Dinophyceae at discharge station were *Ceratium fusus* in spring of 1999, *Ceratium tripos* in autumn of 1999, and *Ceratium* genus such as *Ceratium furca* in summer of 2000. In spring of 2001, *Prorocentrum micans* was dominant at all stations. In spring of 2002, *Prorocentrum micans* and *Prorocentrum minimum* were dominant at intake station. The dominant taxa of Dinophyceae at reference station were *Scrippsiella trochoidea* and

Gonyaulax genus in summer of 2006, *Gumnodinium* genus in spring of 2007 and 2008, and *Alexandrium* genus in spring of 2009.

In addition, other taxa such as Dictyochophyceae, Euglenophyceae, Cyanophyceae, and Chlorophyceae were found, but the biomass was low and their contribution as primary producer was insignificant.

During the period of this study from 1999 to 2009, the annual variation abundance and biomass of Phytoplankton were decreasing (Fig. 2-3, 2-4, 2-5). However, data from 2010 and onward show increased abundance and biomass of Phytoplankton. Therefore decreasing trend of Phytoplankton during the period of this seems to be limited to this particular study period (KHNP, Environment Survey Report). Assessment of long term changes in abundance and biomass of Phytoplankton require further study over a longer time frame which include the period of this study and beyond.

(a)



(b)

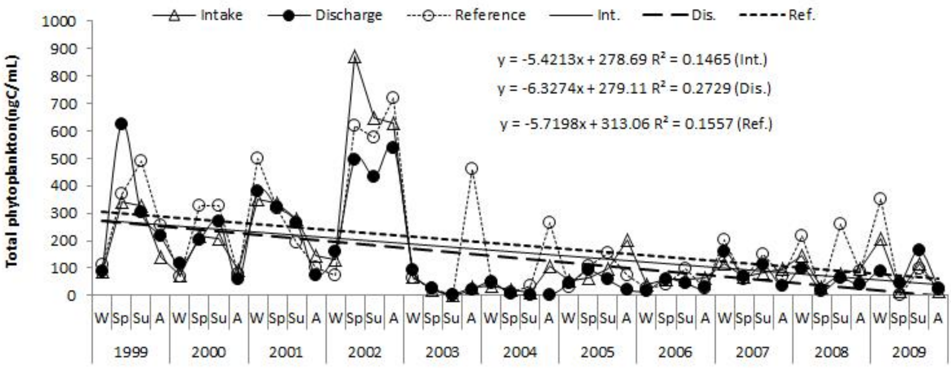
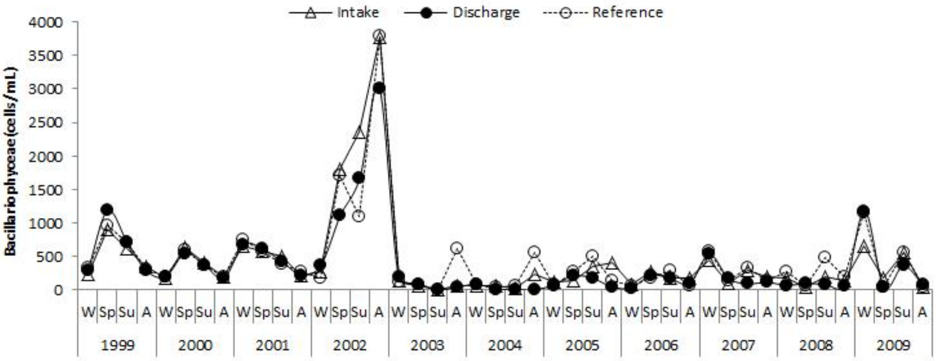


Fig. 2-3. Seasonal variation of total phytoplankton abundance(top) and biomass(down) in the 3 main stations off the Hanbit NPP area from 1999 to 2009 (a) total phytoplankton abundance (cells mL^{-1}) and (b) total phytoplankton biomass (ng C mL^{-1}) (quoted from KHNP raw data)

(a)



(b)

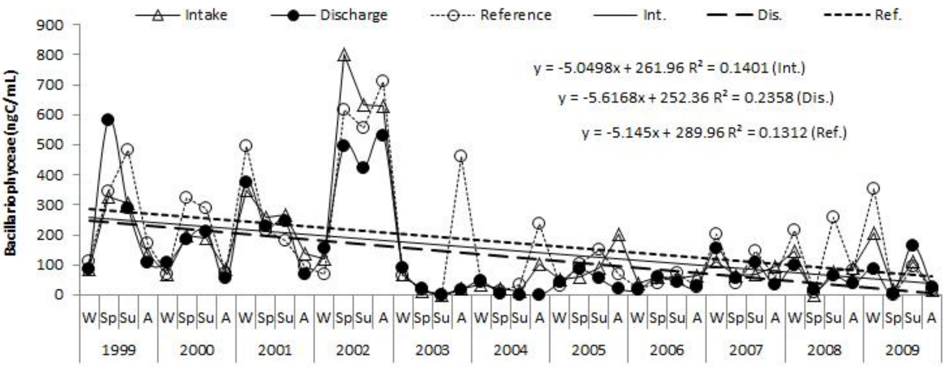
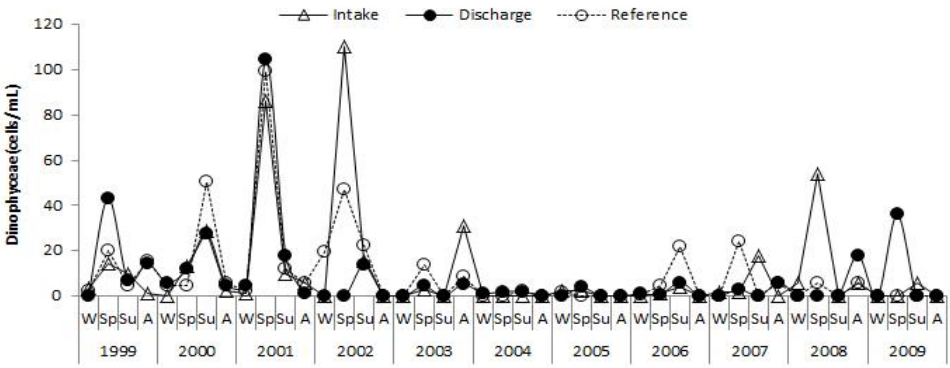


Fig. 2-4. Seasonal variation of Bacillariophyceae in the 3 main stations off the Hanbit NPP area from 1999 to 2009 (a) Bacillariophyceae abundance (cells mL^{-1}) and (b) Bacillariophyceae biomass (ng C mL^{-1}) (quoted from KHNP raw data)

(a)



(b)

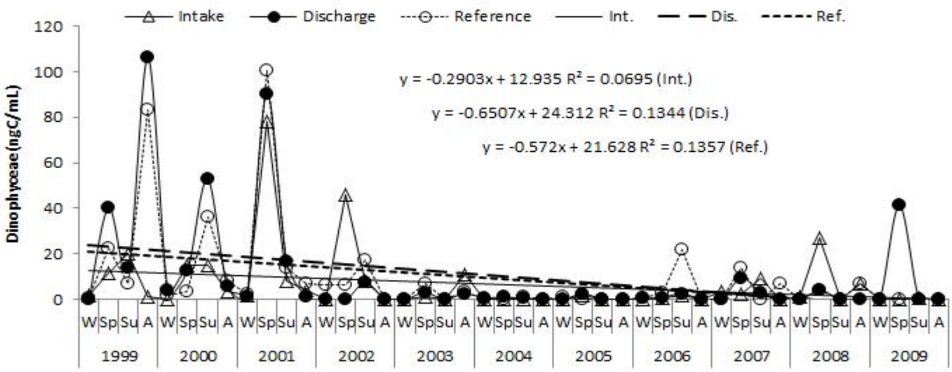


Fig. 2-5. Seasonal variation of Dinophyceae in the 3 main stations off the Hanbit NPP area from 1999 to 2009 (a) Dinophyceae abundance (cells mL^{-1}) and (b) Dinophyceae biomass (ng C mL^{-1}) (quoted from KHNP raw data)

When the abundance of total phytoplankton for each season is compared, relationship of winter < autumn < summer < spring is found(Fig. 2-6). Also, other than in winter, the abundance at the discharge station is certainly lower than intake or reference station. However, when based on the amount of carbon, the biomass in seasons other than winter are similar. Also carbon based biomass is certainly lower in discharge station than intake or reference station in summer and autumn (especially in autumn). Generally, the comparison of abundance shows differences between stations more clearly than comparison of biomass.

Same trend is found in Bacillaiophyceae, which accounted for the largest portion of phytoplankton. The Dinophyceae also showed lower abundance at discharge station than intake or reference station in spring and summer. In winter with lower temperatures, Dinophyceae showed lower abundance and biomass than Bacillaiophyceae. The abundances of other taxa were too low to find such a trend.

The difference in trend of seasonal, average abundances at 3 stations are more visible when I compare the difference of abundance at discharge and intake(Dis-Int in Fig. 2-7) and discharge and reference site(Dis-Ref. in Fig. 2-7). The dominant species at discharge station during winter was mostly *Pararia sulcata.* Other dominant species include *Asterionellopsis kariana* (2000, dominant rate 10.3%), *Thalassiosira decipiens* (2002, 33.3%), *Plagiogramma vanheurckii* (2005, 38.7%), *Rhizosolenia setigera* (2006, 19.0%), *Eucampia zodiacus* (2007, 79.9%), *Skeletonema costatum* (2008, 21.1%), and *Asterionella glacialis* (2009, 52.0%).

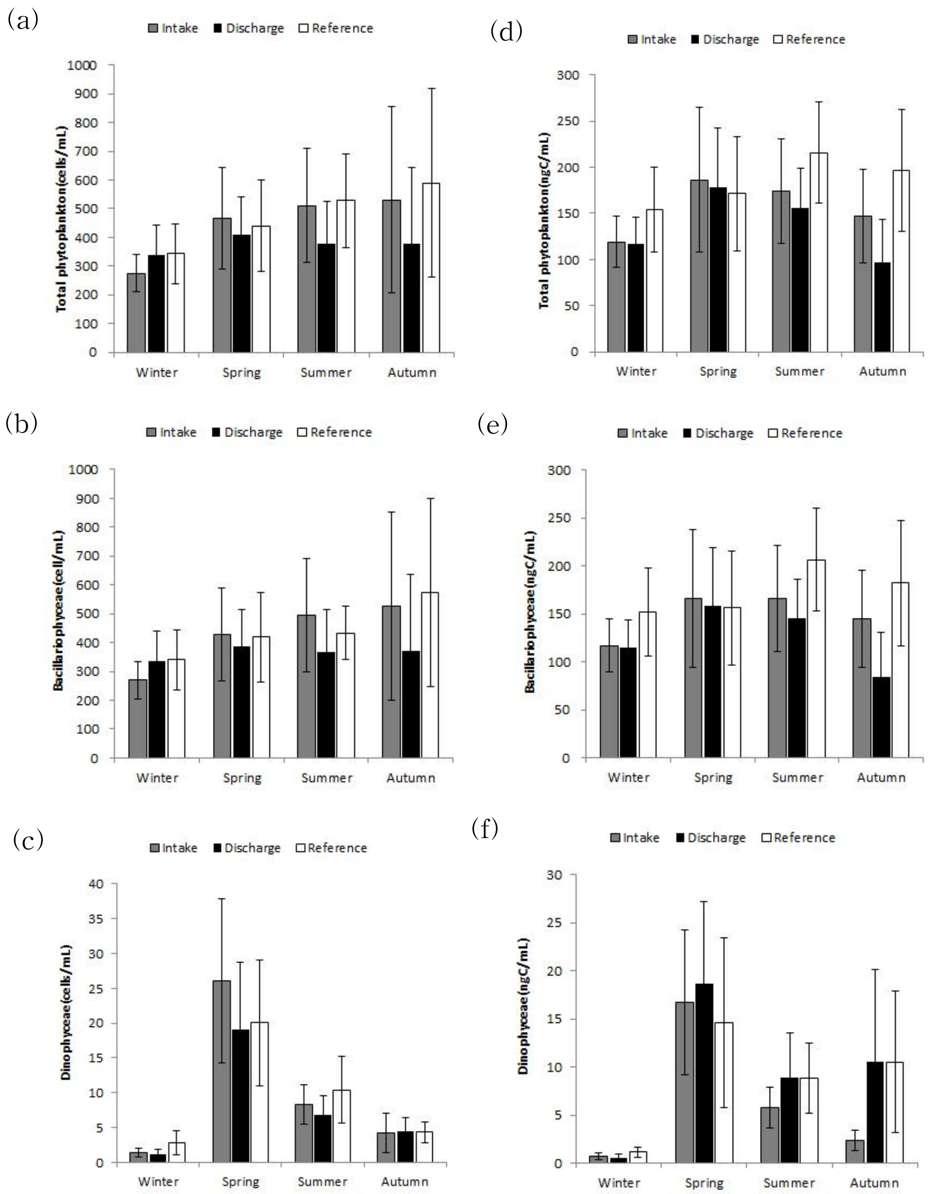


Fig. 2-6. Seasonal average abundance of each taxon at 3 stations (Hanbit). abundance (cells mL^{-1}) of (a) total, (b) Bacillariophyceae, (c) Dinophyceae, biomass (ng C mL^{-1}) of (d) total, (e) Bacillariophyceae, and (f) Dinophyceae (quoted from KHNP raw data)

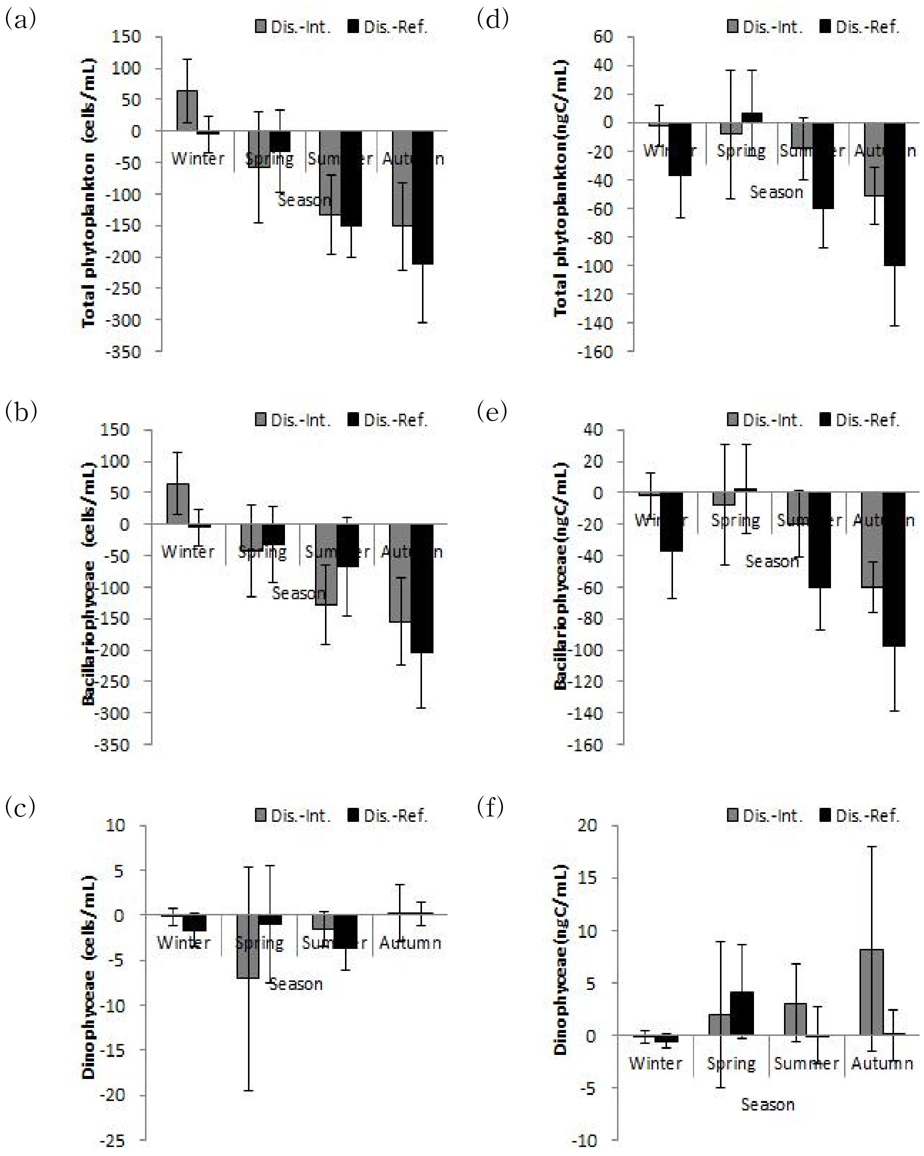


Fig. 2-7. Seasonal average abundance difference of each taxon at 3 stations (Hanbit). abundance difference (cells mL^{-1}) of (a) total, (b) Bacillariophyceae, (c) Dinophyceae, biomass difference (ng C mL^{-1}) of (d) total, (e) Bacillariophyceae, and (f) Dinophyceae (quoted from KHNP raw data)(quoted from KHNP raw data)

Variation of phytoplankton biomass, abundances and temperature

Since this study is focused on relationship between water temperature and phytoplankon communities, after confirming that annual variations of physical and chemical properties are not large, data are re-analyzed based on temperature.

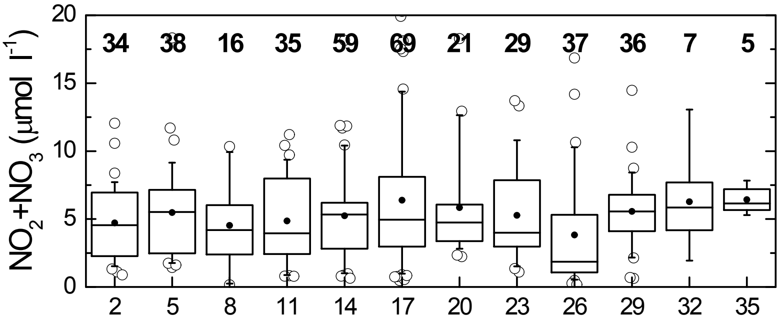
Between 1999 to 2009, temperature varied from 2.4 to 37.6℃ in Hanbit site. Since the water temperature at Hanbit site showed wider range than Hanul site, the temperature range of Hanbit site 2~38℃ were used and data were analyzed with 3℃ intervals. Boxplots are used to find trends in temperature vs. data.

Most of nitrogen compounds exist in the form of nitrate(NO_3). Nitrite(NO_2) is produced from living organism during nitrification and denitrification and is not stable(Spencer 1975). Ammonia(NH_4) is chemically unstable, but is used as source of nitrogen for plant and only found in low concentration in water(Spencer 1975). Therefore the concentration of NO_2+NO_3 is used as measure of DIN(Dissolved Inorganic Nitrogen) in this study.

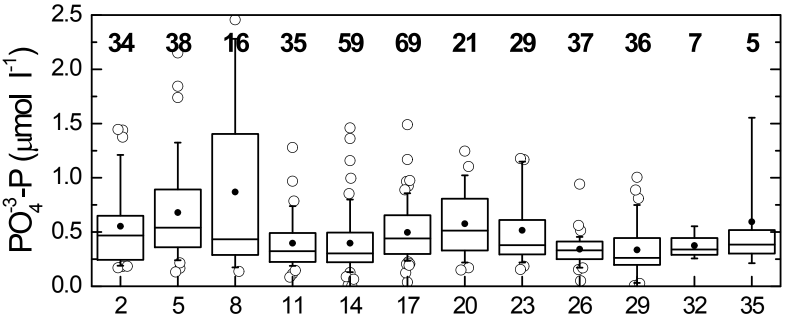
In Hanbit area, DIN concentration was in the range of 0.15 ~ 20.28 umol L^{-1}, DIP(Dissolved Inorganic Phosphate) concentration was in the range of 0.01 ~ 2.46 umol L^{-1}, DSi(Dissolved Silicate) was in the range of 0.21 ~ 26.73 umol L^{-1} (Fig. 2-8).

Data from Hanbit area show positive relationship for DIP and negative relationship for DSi from 2 to 8℃. The weaker relationship for Hanbit might be due to continuous mixing of bottom water nutrient with surface water because of faster current and larger tidal range in Hanbit area.

(a)



(b)



(c)

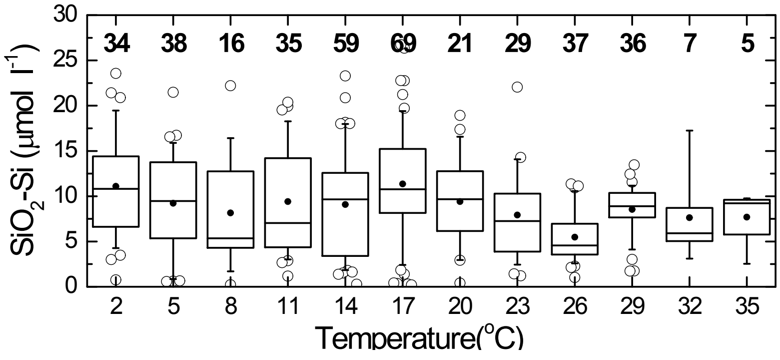


Fig. 2-8. Concentrations of (a) dissolved inorganic nitrogen (DIN), (b) dissolved inorganic phosphate (DIP) and (c) dissolved silicate (DSi) as functions of temperature from 1999 to 2009 in Hanbit site. For the box plots, the boundaries of the boxes represent the 25th and 75th percentile; the solid line within the box is the median; the black dot is the mean; the error bars above and below the box indicate the 10th and 90th percentile, and the points beyond the error bars are the outliers. Number of samples in discrete temp. ranges is given at the top of each panel. (quoted from KHNP raw data)

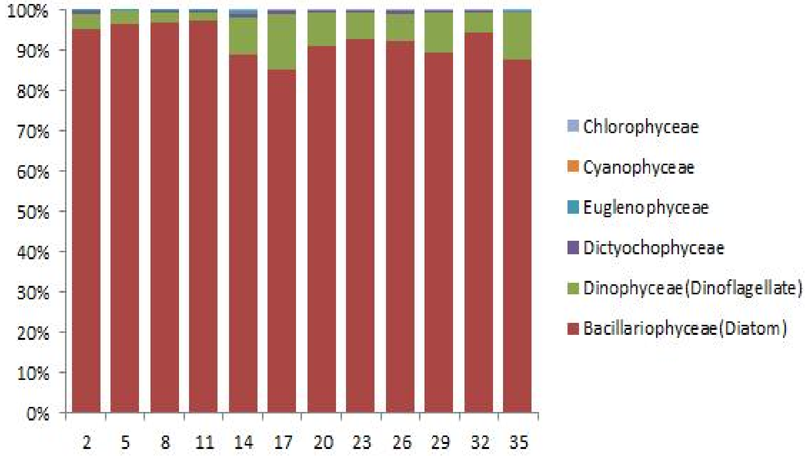
The relative abundance and biomass for phytoplankton vs. temperature are shown in Fig. 2-9. At water temperatures below 11℃, the Hanbit site showed that over 90% of phytoplankon were Bacillaiophyceae. As temperature increased, the fraction of Dinophyceae increased. The increase of Dinophyceae was significant above 14℃ for Hanbit.

In Hanbit area, the changes in total phytoplankton coincides with changes of Bacillaiophyceae, which was the dominant species. Biomass peaks for Bacillaiophyceae were observed at 11℃ and 32℃ for Hanbit(Fig. 2-9 (c)). However, peaks for Dinophyceae were observed at higher temperatures than Bacillaiophyceae with peaks at 14℃, 29℃ and 35℃ for Hanbit(Fig. 2-9 (d)).

In box plot graphs, the outlier means the concentrations of biomass below 10% or over 90% at the temperature. Especially if it was over 90%, it implied mostly blooming had occurred in that temperature range.

Regularity of biomass distribution range with temperature could be found by analyzing mean and 20~75% range of box plots. Exceptional distribution range such as blooming could be identified with outliers.

(a)



(b)

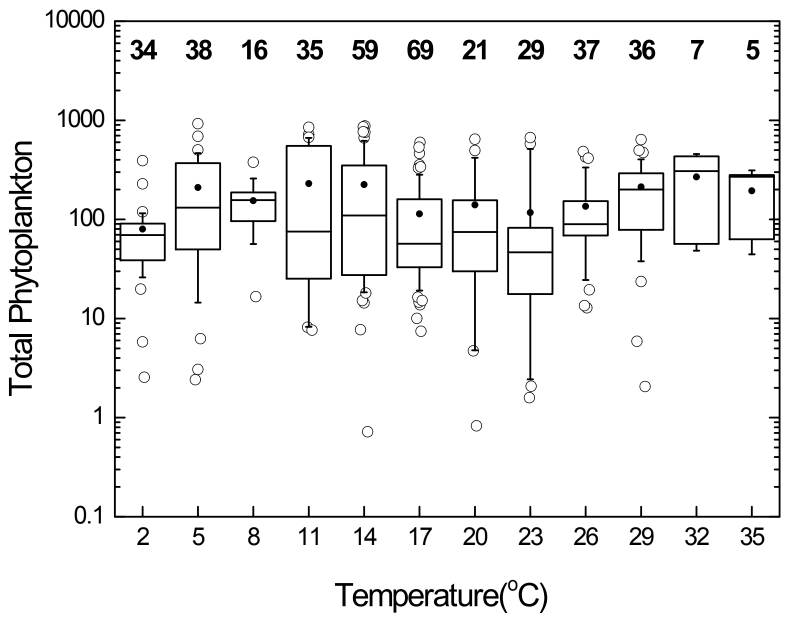
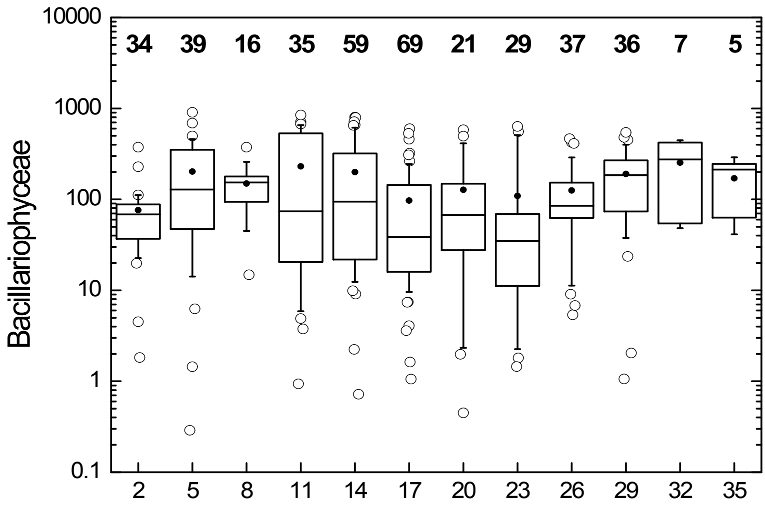


Fig. 2-9. Relative abundance and variation of phytoplankton biomass vs. temperature in Hanbit area (a) relative abundance, (b) total phytoplankton biomass vs. temperature; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

(c)



(d)

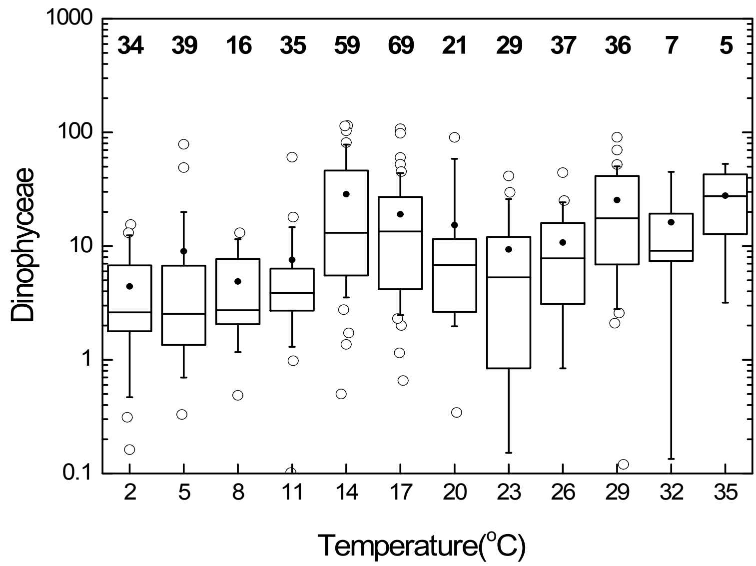


Fig. 2-9(cont.). Relative abundance and variation of phytoplankton biomass vs. temperature in Hanbit area (c) Bacillariophyceae biomass, (d) Dinophyceae biomass vs. temperature; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

variation of chlorophyll *a* concentrations and temperature

The amount of chlorophyll *a* is an important indicator for production capacity of phytoplankton which is the primary producer in marine ecosystem.

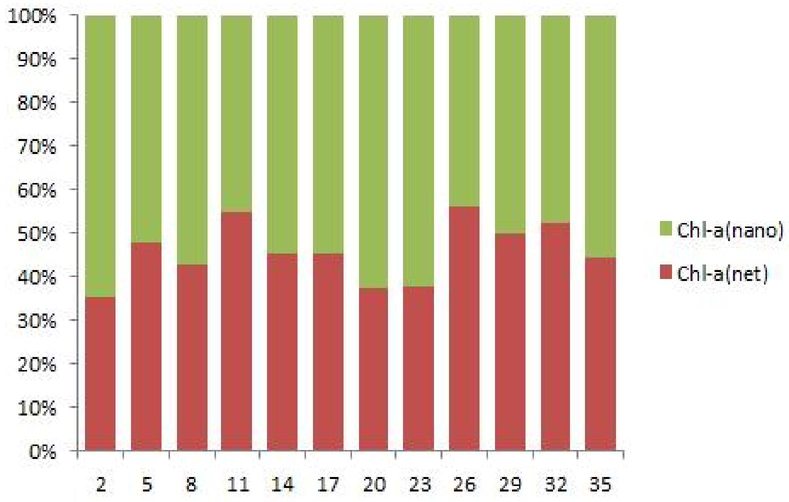
When phytoplanktons were divided into net phytoplankton(larger than 20 microns) and nano phytoplankton(less than 20 microns) and chlorophyll *a* was compared with water temperature, data from Hanbit showed net peak values at 11℃ and 26-29℃. At temperatures where the phytoplankton abundance was high, the chlorophyll *a* of net plankton was dominant. At low temperatures and very high temperature (above 35℃ in Hanbit), chlorophyll *a* of nano plankton was dominant(Fig. 2-10 (a)).

The total concentration of chlorophyll *a* in Hanbit area had range of 0.48 ~ 27.10 ug L^{-1}(Fig. 2-10 (b)).

To quantify the effect of growth inhibition, growth inhibition ratio was calculated based on changes in concentration of chlorophyll *a* at the intake and discharge. For discharge, the sampling point was chosen at front discharge to measure changes in chlorophyll *a* concentration of water that passed through the condenser.

The annual(1999~2009), seasonal variations of phytoplankton growth inhibition ratio, calculated from changes in concentration of chlorophyll *a* at the intake and front discharge, are shown in table 2-5. The annual mean inhibition ratio was lowest in 2004 and highest in 2008. In 2009, large negative inhibition ratio was observed in spring.

(a)



(b)

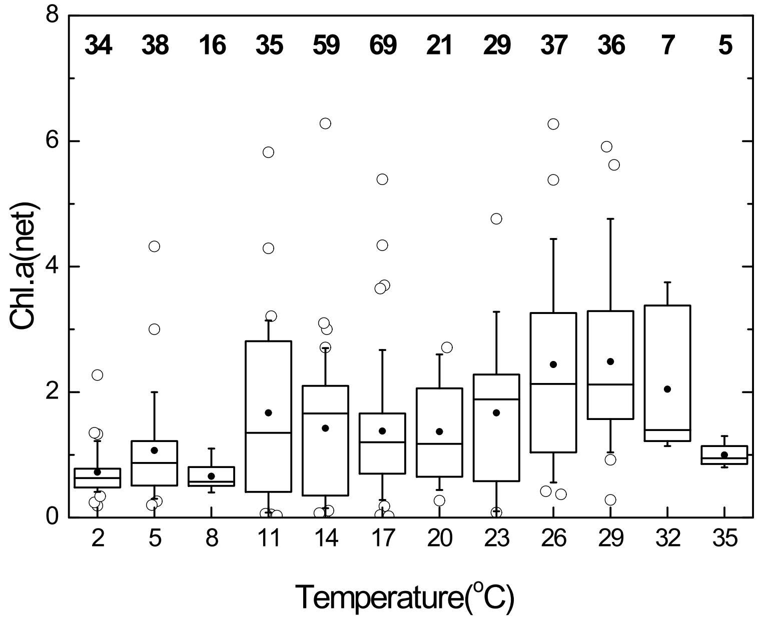


Fig. 2-10. Relative concentrations and variation of chlorophyll *a* concentrations vs. temperature in Hanbit area (a) relative concentrations, (b) chlorophyll *a* concentrations vs. temperature; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

Table 2-5. Phytoplankton growth inhibition ratio(%) of Hanbit NPP cooling systems (quoted from KHNP data).

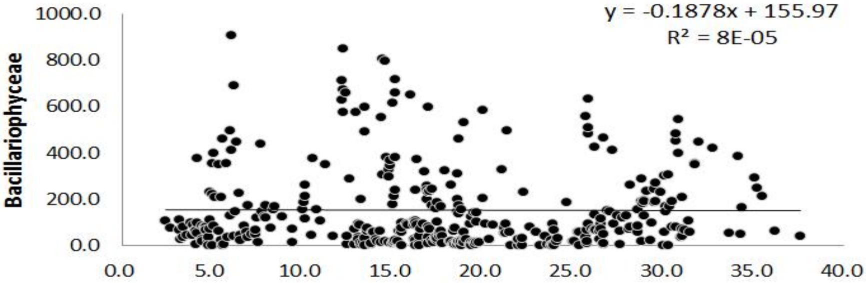
season / year	winter	spring	summer	autumn	mean
1999	33.12	37.00	47.0	61.8	44.7
2000	16.2	49.2	54.7	40.7	40.2
2001	42.8	36.3	50.3	35.4	41.2
2002	47.4	34.1	42.9	42.1	41.6
2003	21.8	24.3	32.2	74.2	38.1
2004	-58.3	26.0	56.7	-6.5	4.5
2005	14.4	34.4	60.8	-24.6	21.3
2006	62.6	48.9	70.7	-0.04	45.5
2007	26.4	43.9	54.8	27.1	38.1
2008	75.2	20.2	79.1	36.8	52.8
2009	81.7	-119.0	51.6	32.1	11.6
mean	33.0	21.4	54.6	29.0	34.5

Variation of phytoplankton major dominants and temperature

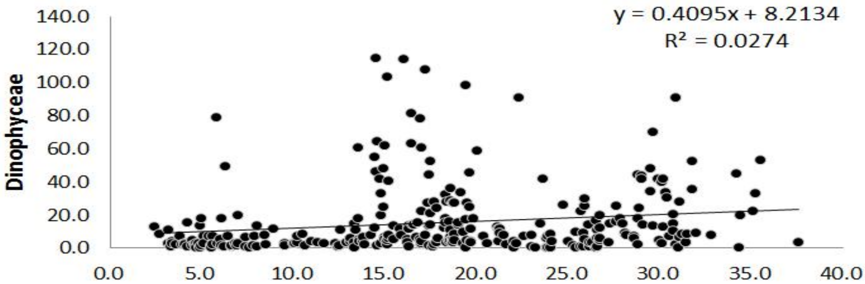
The medium term variations in the biomass and abundance of dominant species during 11 year period from 1999 to 2009 at Hanbit site were shown in Appendix Table A-1. Each species of plankton may appear at different time, but when data are rearranged according to temperature, the results are shown in Fig. 2-11. At Hanbit area, Diatom decreased with increase in temperature and Dinoflagellate increased with increase in temperature.

Dominant species appeared at various temperatures were as follows. *Asterionella* spp.(including *A. formosa, A. glacialis* and *A. kariana*) showed high abundance in low temperatures. *Thalassiosira* spp. showed high abundance in temperatures 10-15℃. Around 15℃ where blooming is likely to occur, high abundance in Dictyochophyceae, Euglenophyceae, *Rhizosolenia* spp. *Skeletonema costatum* was found. *Prorocentrum micans* and *Prorocentrum minimum* which are Dinoflagellates also showed high abundance above 15 ℃. *Scrippsiella trochoidea* showed high abundance around 15℃. *Navicula* spp. showed high abundance around 15-20℃ and *paralia sulcata* showed high abundance in Hanbit area at 15℃. *Cheatoceros* spp.(inclding *C. curvisetus, C. danicus, D. debilis* and others) showed high abundance at 25-35℃. *Leptocylindrus* spp. showed high abundance at 32℃ in Hanbit area. *Nitzchia* spp. is eurythermal algae, but showed high abundance at 32℃. *Ceratium* spp. which is Dinoflagellate also showed high abundance at 32℃. Chlorophyceae generally showed low abundance, although abundance increased with increase in temperature. The species that showed eurythermal distribution were *Cylindrotheca closterium*, *Eucampia* spp.(mostly *E. zodiacus*) and *Nitzchia* spp.

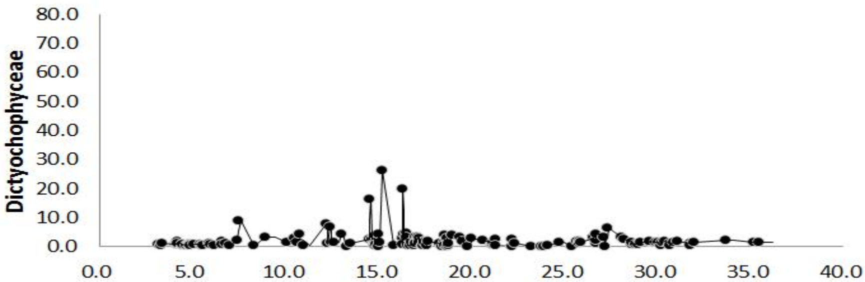
(a)



(b)



(c)



(d)

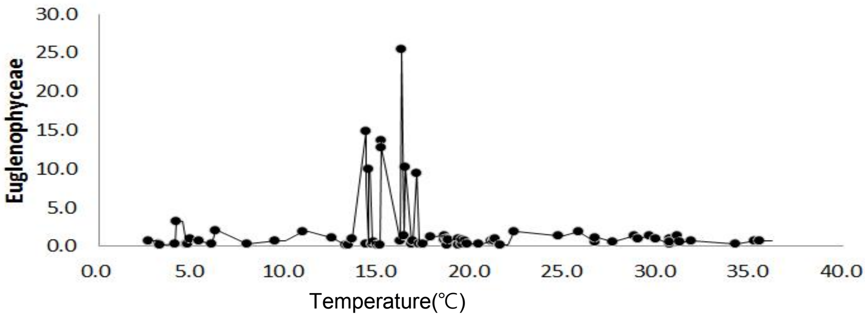
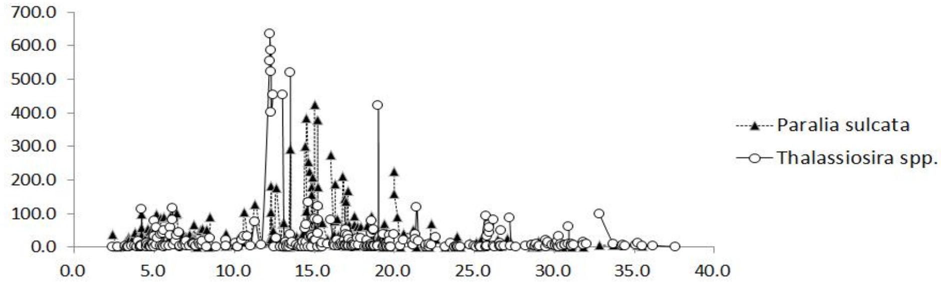
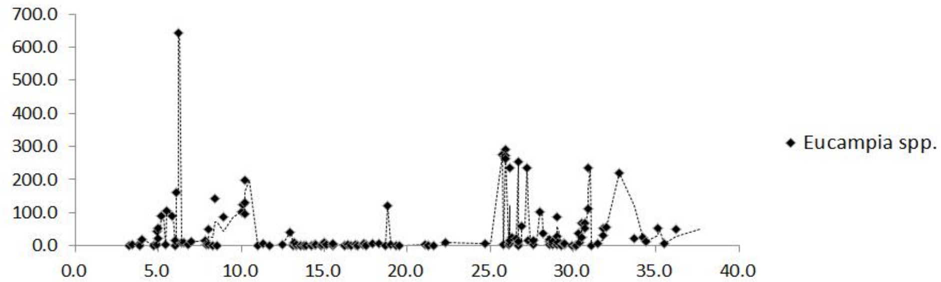


Fig. 2-11. Changes in biomass as function of temperature for Hanbit site (a) Bacillariophyceae, (b) Dinophyceae, (c) Dictyochophyceae and (d) Euglenophyceae (y axis unit : n C mL^{-1}) (quoted from KHNP raw data)

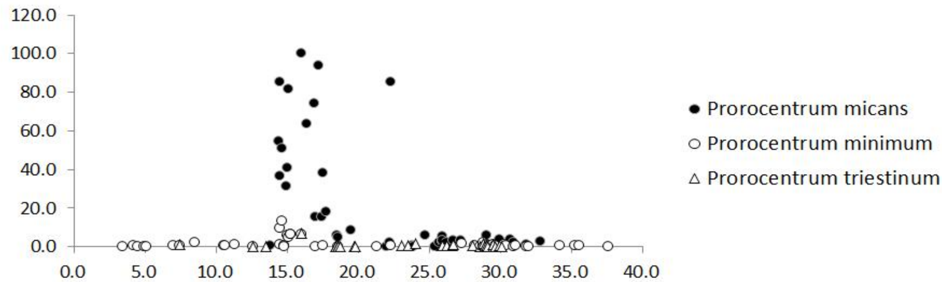
(e)



(f)



(g)



(h)

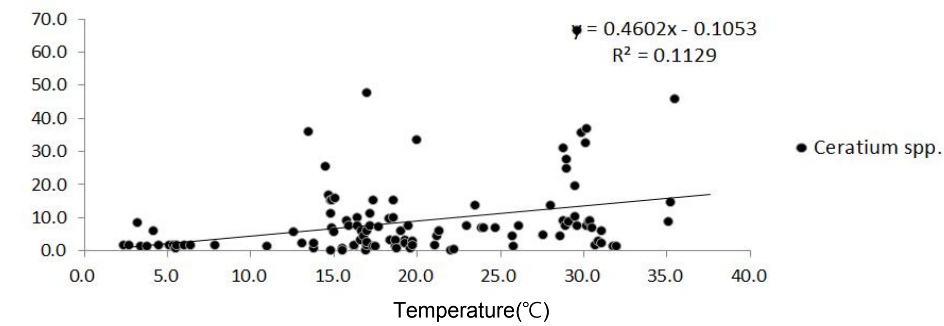


Fig. 2-11(cont.). Changes in biomass as function of temperature for Hanbit site (e) *Paralia sulcata*(▲), *Thalassiosira* spp(○), (f) *Eucampia* spp.(◆) (g) *Prorocentrum micans*(●), *P. minimum*(○), *P. triestinum*(△) and (h) *Ceratium* spp. (●) (y axis unit : n C mL^{-1}) (quoted from KHNP raw data)

2-3-2. Characteristics of Hanul site

Physicochemical properties

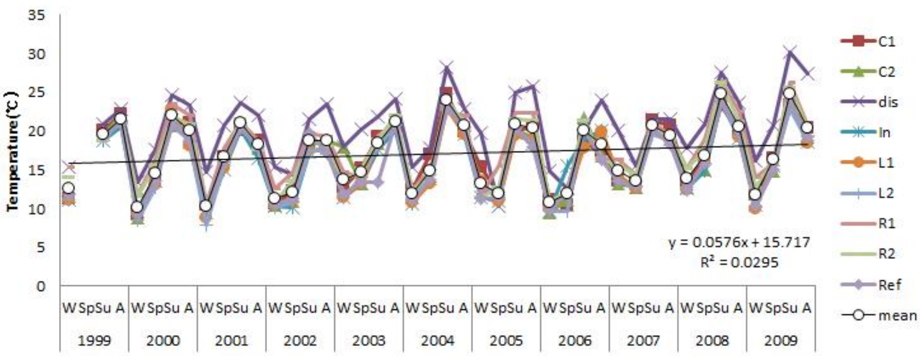
At Hanul site, between 1999 to 2009, temperature varied from 7.8 to 30.2℃; transparency varied from 1.5 to 18.0 m; pH varied from 7.4 to 8.5; DO varied from 5.5 to 13.9 mg L^{-1}; COD varied from 0.27 to 2.36 mg L^{-1}; SS varied from 1.7 to 26.0 mg L^{-1}(Fig. 2-12).

In comparison with Hanbit NPP area on west coast, the water temperature in Hanul NPP area showed smaller changes because of deeper sea and smaller tidal range. So the Hanul NPP area had higher transparency and lower SS than Hanbit NPP area.

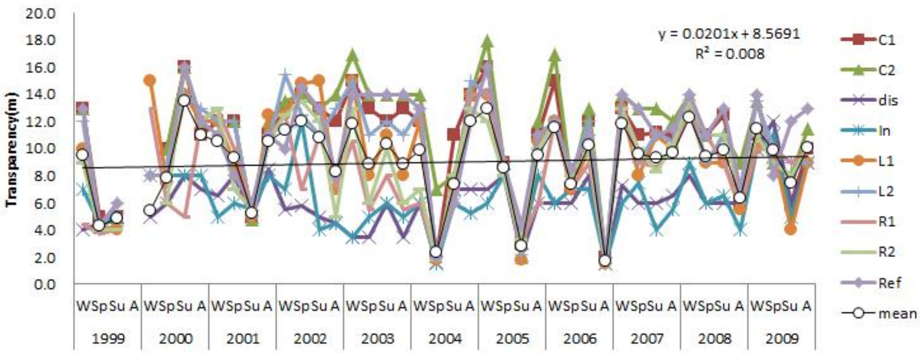
The SS and COD have decreased slightly for Hanul. The DO has decreased slightly for both sites, and this is related to the increase of temperature, which showed similar trends to Hanbit site.

The water temperature in Hanul NPP area showed smaller changes than west coast. The transparency of intake and discharge were similar and that of reference station was higher than other stations. The pH and DO were lower at discharge station. The SS also showed different trend compared with Hanbit NPP area.

(a)



(b)



(c)

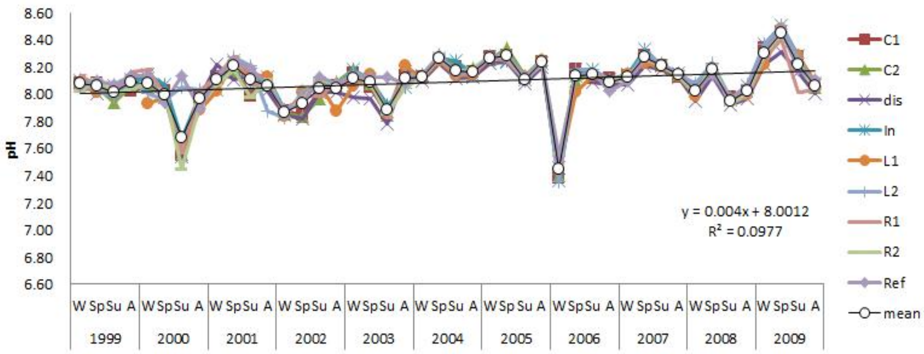
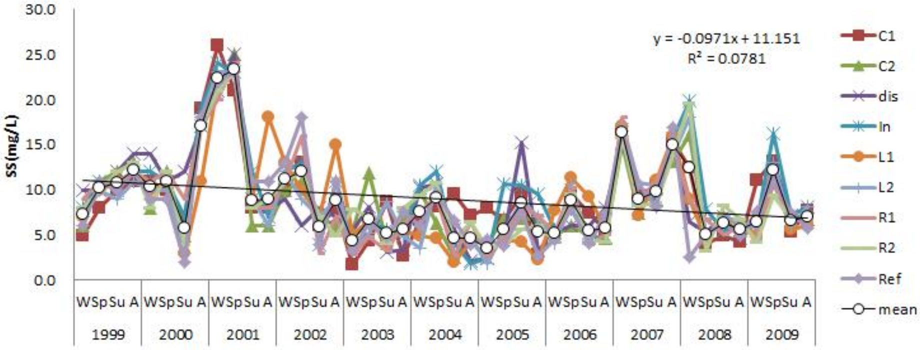
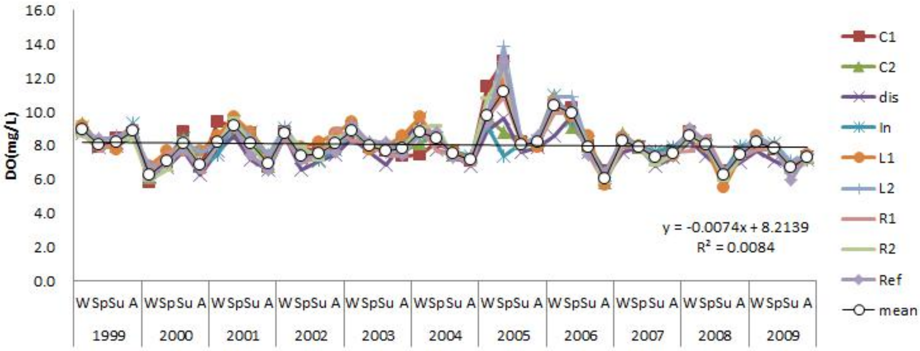


Fig. 2-12. Annual, seasonal variation of physicochemical properties in Hanul NPP area (a) Temperature(℃), (b) Transparency(m) and (c) pH (quoted from KHNP raw data)

(d)



(e)



(f)

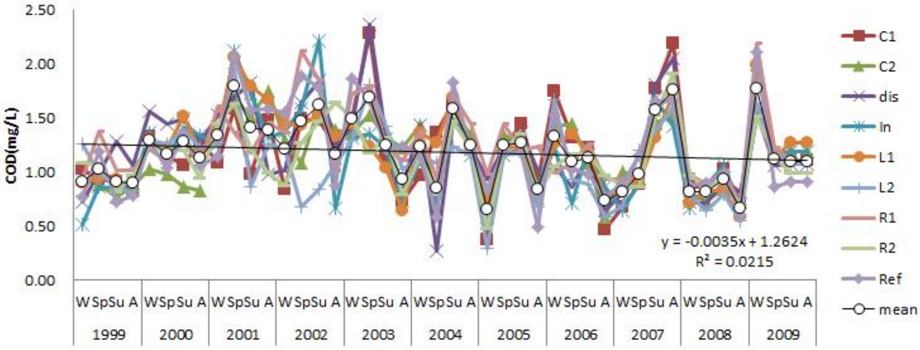


Fig. 2-12(cont.). Annual, seasonal variation of physicochemical properties in Hanbit NPP areas (d) SS(mg L^{-1}), (e) DO(mg L^{-1}) and (f) COD(mg L^{-1}) (quoted from KHNP raw data)

Seasonal/annual variation in abundance and biomass of phytoplankton

Seasonal/annual variation in abundance and biomass of Hanul site phytoplankton were compared. The biomass was calculated from abundance of each species and known carbon content of each species.

In Hanul area, total phytoplankton's biomass and abundance ranged from 0.2 ng C mL^{-1} (1.0 cells mL^{-1}) to 255.3 ng C mL^{-1} (1,416.7 cells mL^{-1}). Bacillaiophyceae ranged from 0.1 ng C mL^{-1} (0.3 cells mL^{-1}) to 197.6 ng C mL^{-1} (1,409.5 cells mL^{-1}), Dinophyceae ranged from 0.1 ng C mL^{-1} (0.2 cells mL^{-1}) to 146.0 ng C mL^{-1} (160.8 cells mL^{-1}), Dictyochophyceae ranged from 0.1 ng C mL^{-1} (0.1 cells mL^{-1}) to 69.2 ng C mL^{-1} (127.2 cells mL^{-1}), Euglenophyceae ranged from 0.1 ng C mL^{-1} (0.1 cells mL^{-1}) to 10.7 ng C mL^{-1} (39.6 cells mL^{-1}), Cyanophyceae ranged from 0.1 ng C mL^{-1} (0.3 cells mL^{-1}) to 1.2 ng C mL^{-1} (61.2 cells mL^{-1}) (Table 2-6).

Appendix Table A-2 showed the maximum biomass and abundance of the top dominant species in Hanul NPP from 1999 to 2009. This showed the effect of temperature on dominant species.

Table 2-6. The range of abundance and biomass of each phytoplankton group and the water temperature, pH, DO and SS in Hanul area (quoted from KHNP raw data)

Taxa	T (℃)	pH	DO ($mg\ L^{-1}$)	SS ($mg\ L^{-1}$)	Abundance ($cells\ mL^{-1}$)	Biomass ($ng\ C\ mL^{-1}$)
Total phytoplankton	7.8-30.2	7.4-8.5	5.5-13.0	1.7-26.0	1.0-1,416.7	0.2-255.3
Bacillariophyceae	7.8-30.2	7.4-8.5	5.5-13.0	1.7-26.0	0.3-1,409.5	0.1-197.6
Dinophyceae	7.8-30.2	7.4-8.5	5.5-13.0	1.7-26.0	0.2-160.8	0.1-146.0
Dictyochophyceae	7.8-25.8	7.4-8.5	5.7-13.0	1.7-25.0	0.1-127.2	0.1-69.2
Euglenophyceae	9.5-27.6	7.4-8.5	5.5-13.0	1.7-25.0	0.1-39.6	0.1-10.7
Cyanophyceae	8.5-23.7	7.6-8.3	5.8-9.3	2.7-23.0	0.3-61.2	0.1-1.2

Seasonal/annual variation in abundance and biomass of phytoplankton were compared at intake, discharge and reference stations. The intake station of Hanul nuclear power plant of biomass and abundance of total phytoplankton during 1999 to 2009, ranged from minimum of 1.1 ng C mL^{-1}(2 cells mL^{-1}) to maximum of 175 ng C mL^{-1}(1,417 cells mL^{-1}). The discharge station is located 1.5 km north east of the intake site. The biomass and abundance of phytoplankton during 1999 to 2009, ranged from minimum of 0.2 ng C mL^{-1} (2 cell mL^{-1}) to maximum of 197.2 ng C mL^{-1} (821 cells mL^{-1}). The reference station is located 6 km south east of Hanul nuclear power plant. The biomass and abundance of phytoplankton during 1999 to 2009, ranged from minimum of 0.4 ng C mL^{-1} (1 cells mL^{-1}) to maximum of 153.4 ng C mL^{-1}(888 cells mL^{-1}) (Fig.2-13).

A large blooming of phytoplankton was observed in 2003. During spring seasons, the dominant species were *Leptocylindrus danicus* (50~80%) for all stations. In spring of 2005, the dominant species were *Thalassiosira rotura* (34.3%) for intake station, *Chaetoceros debilis* for discharge station(35.8%) and reference station (29.2%).

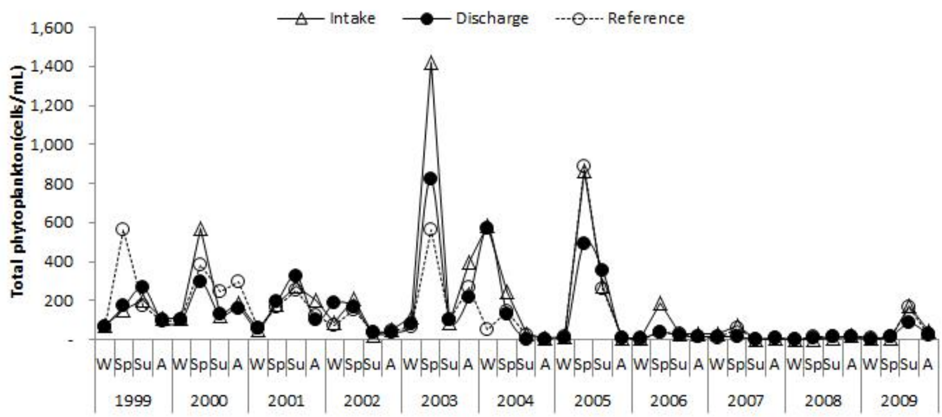
The Bacillariophyceae dominated phytoplankton and their biomass and abundance ranged from 0.4 ng C mL^{-1}(1.0 cells mL^{-1}) to 169.9 ng C mL^{-1}(1,409.5 cells mL^{-1}) in intake station, from 0 ng C mL^{-1}(0 cell mL^{-1}) to 108.4 ng C mL^{-1}(799.5 cells mL^{-1}) in discharge station and from 0.3 ng C mL^{-1}(1.0 cells mL^{-1}) to 106.7 ng C mL^{-1}(754.9 cells mL^{-1}) in reference station(Fig.2-14).

The next dominant taxon was Dinophyceae and their biomass and abundance during 1999 to 2009, ranged from minimum of 0.5 ng C mL^{-1}(1 cell mL^{-1}), to maximum of 60.2 ng C mL^{-1}(156.4 cells mL^{-1}) in intake station, ranged from minimum of 0.5 ng C mL^{-1}(1 cell mL^{-1}), to maximum of 130.3 ng C mL^{-1}(153.6 cells mL^{-1}) in discharge station, and ranged from minimum of 0.5 ng C mL^{-1}(1.0 cells mL^{-1}) to maximum of 68.7 ng C mL^{-1}(129.4 cells mL^{-1}) in reference station(Fig.2-15).

For Hanul area in spring of 1999, the dominant species at reference station was *Leptocylindrus danicus* which belongs to Bacillariophyceae, with abundance of 410.4 cell L^{-1} (73.4%). At intake station, *Licmophora abbreviata*, was dominant with 22.6%, followed by *Ceratium* genus. At discharge station, *Ceratium fusus* was dominant with 30.2%.

During the period of this study from 1999 to 2009, the annual variation abundance and biomass of Phytoplankton in Hanul area were also decreased (Fig. 2-13, 2-14, 2-15). However, data observed after the study period showed increased abundance and biomass of Phytoplankton(KHNP Environment Survey Report). Therefore decreasing trend of Phytoplankton during the period of this study seemed to be limited to this particular study period. Assessment of long term changes in abundance and biomass of Phytoplankton is required in further study over a longer time frame which includes the period of this study and beyond.

(a)



(b)

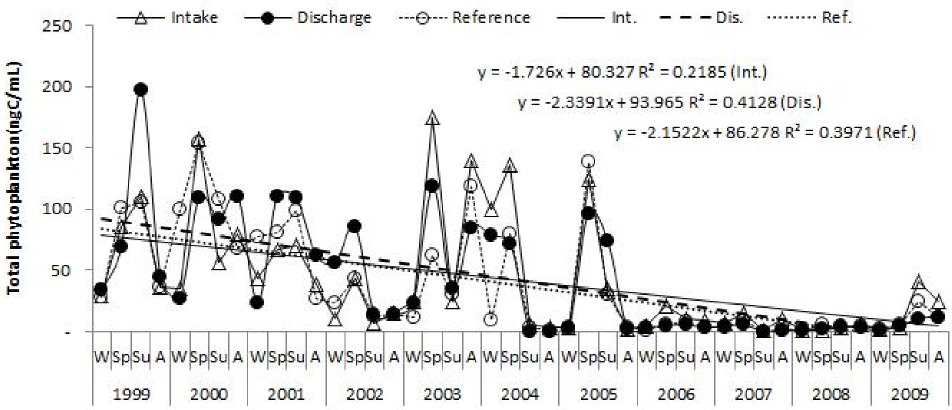
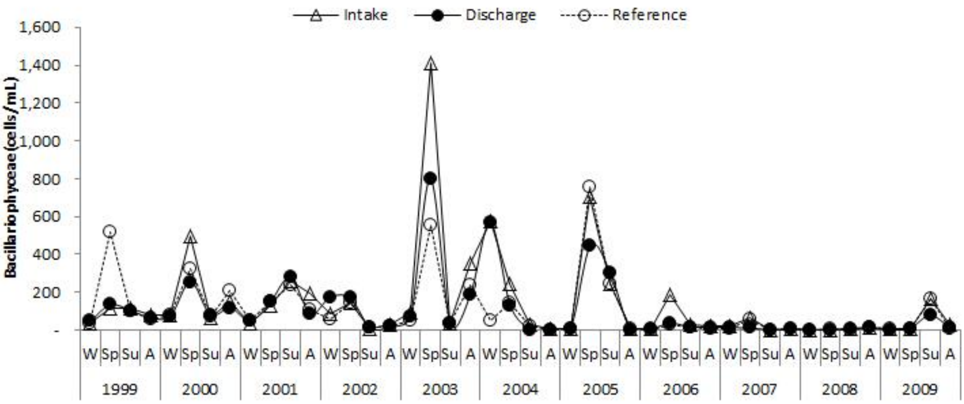


Fig. 2-13. Seasonal variation of total phytoplankton abundance and biomass in the 3 main stations off the Hanul NPP area from 1999 to 2009 (a) total phytoplankton abundance (cells mL^{-1}) and (b) total phytoplankton biomass (ng C mL^{-1}) (quoted from KHNP raw data)

(a)



(b)

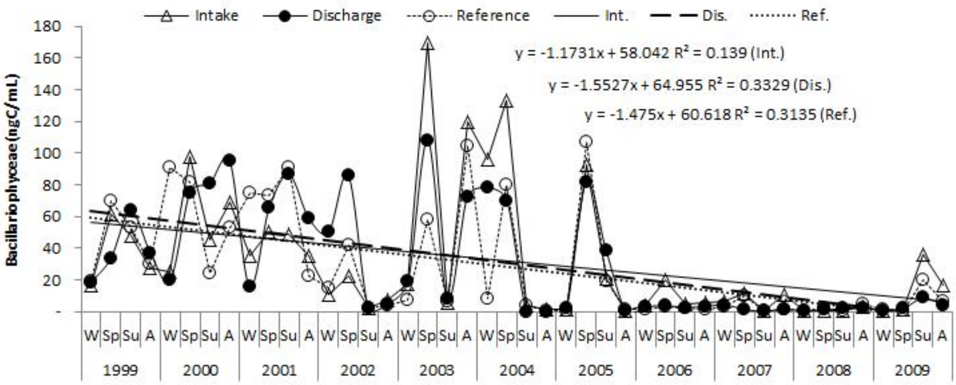
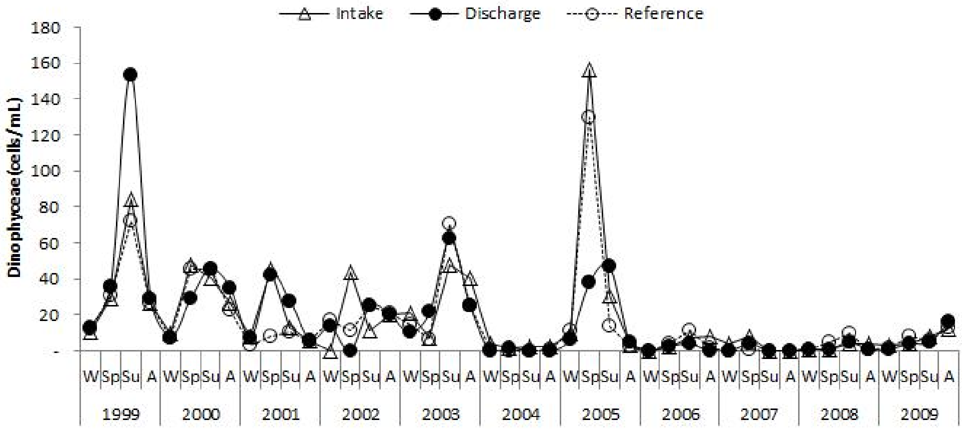


Fig. 2-14. Seasonal variation of Bacillariophyceae in the 3 main stations off the Hanul NPP area from 1999 to 2009 (a) Bacillariophyceae abundance (cells mL^{-1}), (b) Bacillaiophyceae biomass (ng C mL^{-1}) (quoted from KHNP raw data)

(a)



(b)

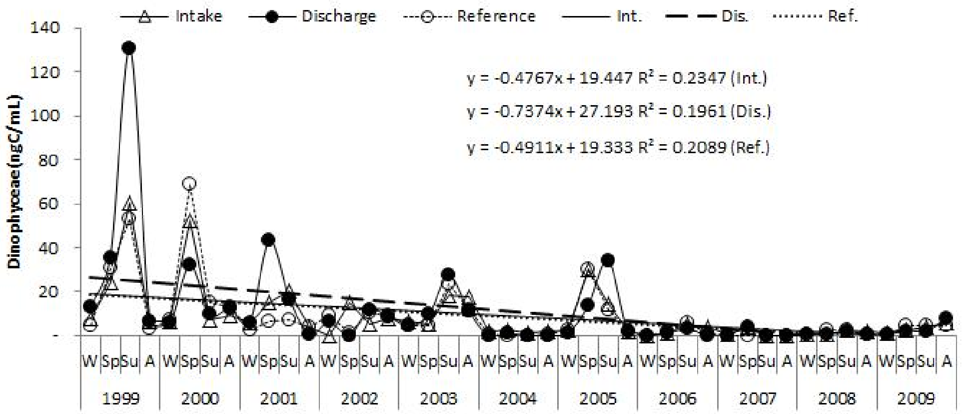


Fig. 2-15. Seasonal variation of Dinophyceae in the 3 main stations off the Hanul NPP area from 1999 to 2009 (a) Dinophyceae abundance (cells mL^{-1}), (b) Dinophyceae biomass (ng C mL^{-1}) (quoted from KHNP raw data)

The comparison of seasonal abundance of total phytoplankton showed that the relationship of abundance was winter < autumn < summer < spring(Fig.2-16). Also, no significant differences between intake, discharge and reference stations were found. Even if abundance of each taxon was compared, no significant trend was observed. One minor trend observed was that, in general, biomass at discharge in spring was low, and same trend was observed for biomass of diatoms and Dinophyceae. For Dinophyceae, the biomass was higher at discharge than other location in summer, but this was based on average values and would be difficult to identify a definite trend. The lack of any special trend on seasonal and site specific abundance was clearly shown in comparison of abundance between discharge-intake and between discharge-reference(Fig. 2-17). This was confirmed in comparison of abundance between discharge-intake and between discharge-reference.

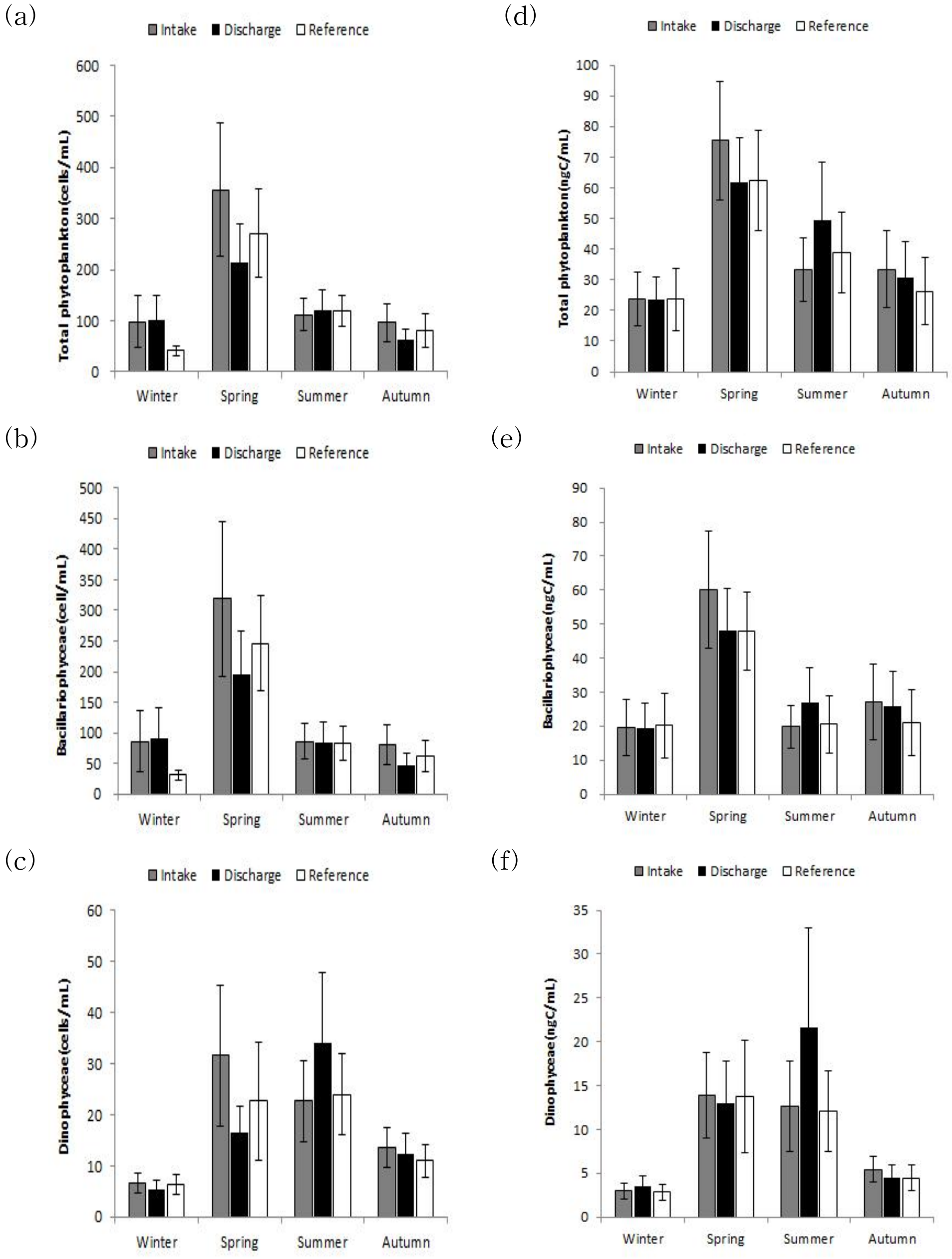


Fig. 2-16. Seasonal average abundance of each taxon at 3 stations (Hanul). abundance (cells mL^{-1}) of (a) total, (b) Bacillariophyceae, (c) Dinophyceae, biomass (ng C mL^{-1}) of (d) total, (e) Bacillariophyceae, and (f) Dinophyceae (quoted from KHNP raw data)

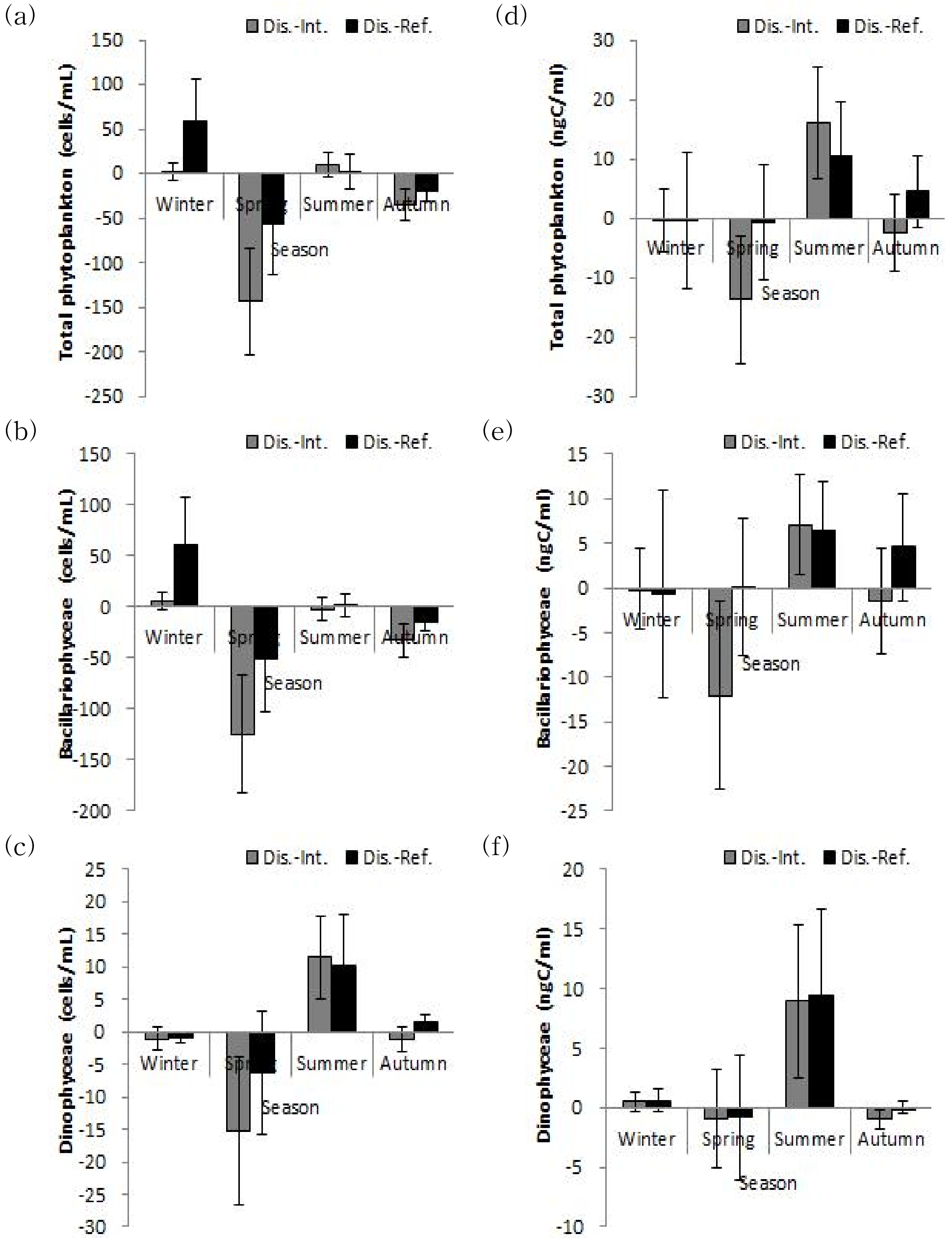


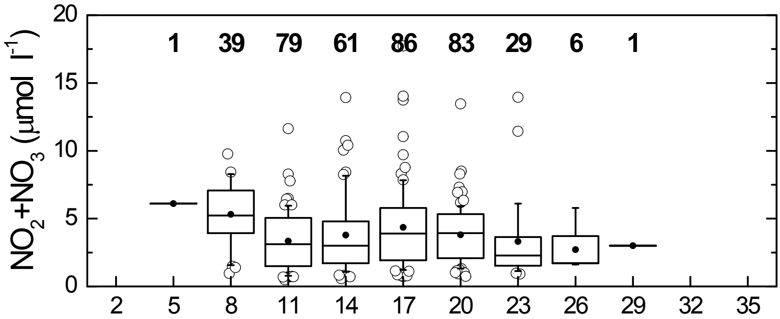
Fig. 2-17. Seasonal average abundance difference of each taxon at 3 stations (Hanul). abundance difference (cells mL^{-1}) of (a) total, (b) Bacillariophyceae, (c) Dinophyceae, biomass difference (ng C mL^{-1}) of (d) total, (e) Bacillariophyceae, and (f) Dinophyceae (quoted from KHNP raw data)(quoted from KHNP raw data)

Variation of phytoplankton biomass, abundances and temperature

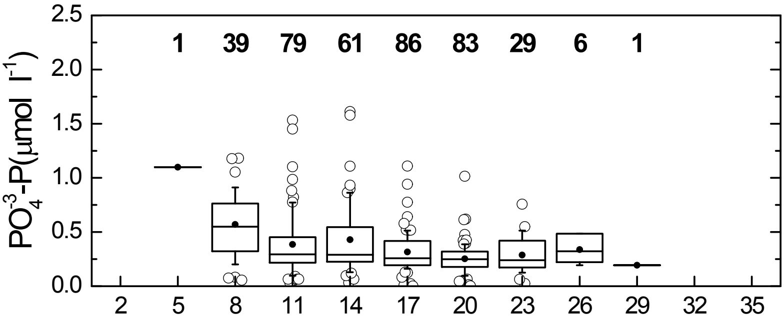
Between 1999 to 2009, temperature varied from 7.8 to 30.2℃ in Hanul site. In Hanul area, DIN concentration were in the range of 0.5 ~ 17.73 umol L^{-1}, DIP concentration were in the range of 0.001 ~ 1.61 umol L^{-1}, DSi concentration were in the range of 0.09 ~ 17.17 umol L^{-1}(Fig. 2-18).

In comparison of nutrients with temperature, there was a negative inverse relationship between temperature and DIN, DIP and DSi from 5 to 11℃ in Hanul site.

(a)



(b)



(c)

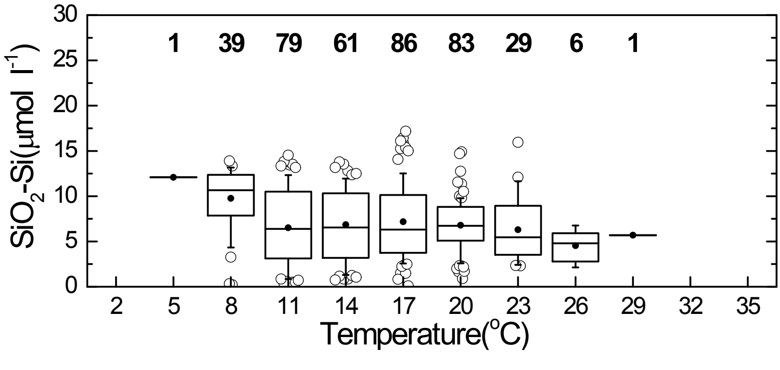


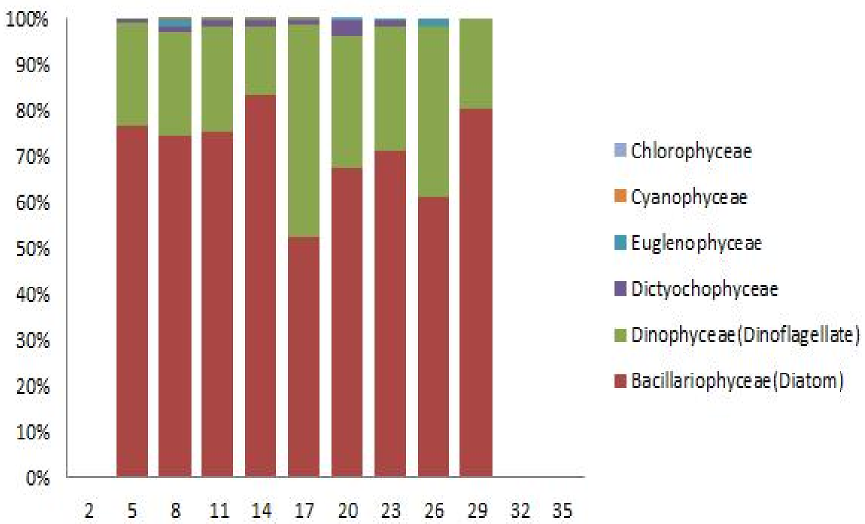
Fig. 2-18. Concentrations of (a) dissolved inorganic nitrogen (DIN), (b) dissolved inorganic phosphate (DIP) and (c) dissolved silicate (DSi) as functions of temperature from 1999 to 2009 in Hanul site; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

The relative abundance and biomass for photoplankton vs. temperature are shown in Fig.2-16 (a), (b). At water temperatures below 11℃, Hanul site showed about 75% of phytoplankon were Bacillaiophyceae. As temperature increased, the fraction of dinoflagellate increased. The increase of dinoflagellate was significant above 17℃ for Hanul.

In both sites, the changes in total phytoplankton coincided with changes of diatom, which is the dominant species. Biomass peaks for diatom were observed at 14℃ and 20℃ for Hanul (Fig. 2-19 (c)). For Hanul, the biomass of dinoflagellate increased from 14℃ to 20℃ and decreased above 20℃(Fig. 2-19 (d)).

Previous study reported negative correlation with temperature for diatoms, and positive correlation with temperature for dinoflagellate(Xie et al, 2015). However, the western English Channel, which was used as site for the previous study, had smaller temperature variation (7.3~18.2℃) than current study and this smaller temperature variation resulted in linear relationship with temperature. In current study, dinoflagellate also stopped increasing above 20℃.

(a)



(b)

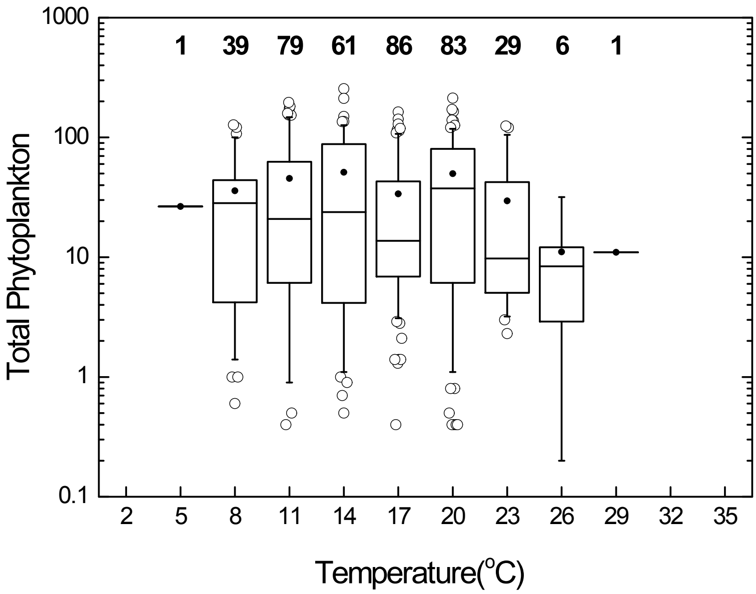
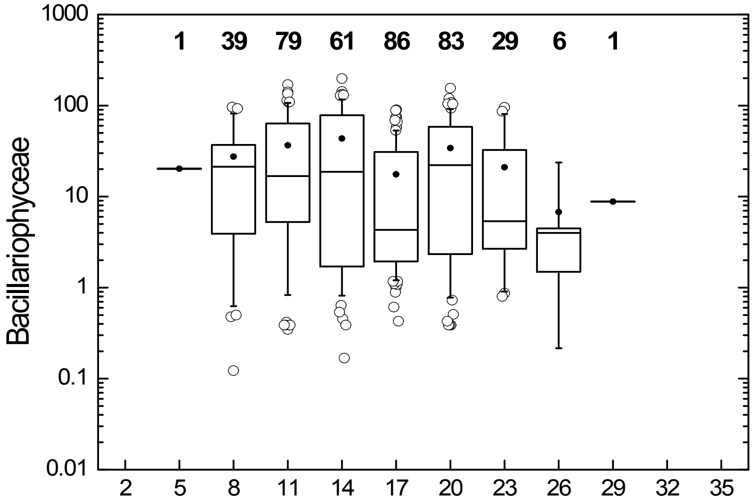


Fig. 2-19. Relative abundance and variation of phytoplankton biomass vs. temperature in Hanul area (a) relative abundance, (b) total phytoplankton biomass vs. temperature; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

(c)



(d)

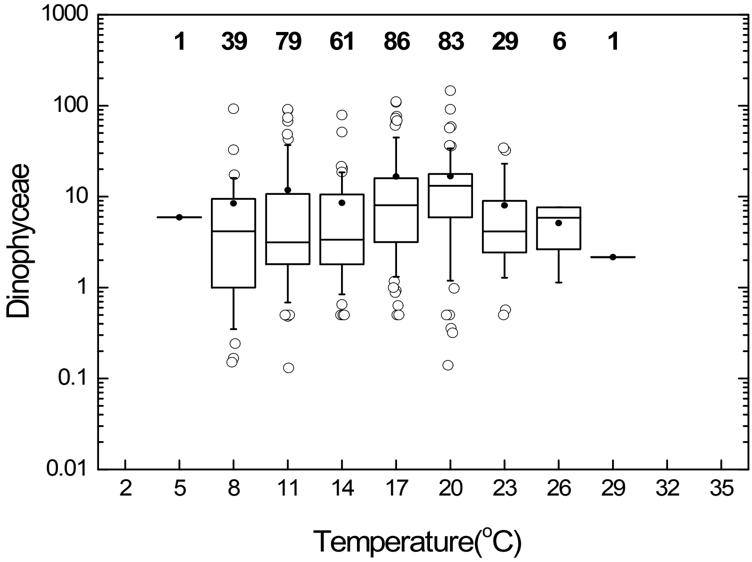


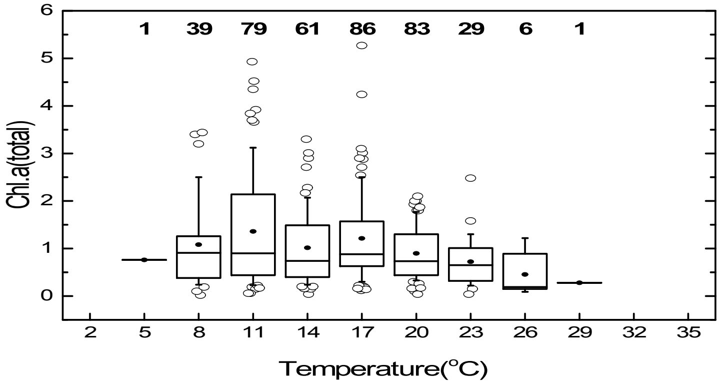
Fig. 2-19(cont.). Relative abundance and variation of phytoplankton biomass vs. temperature in Hanul area (c) Bacillariophyceae biomass, (d) Dinophyceae biomass vs. temperature; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

Variation of chlorophyll *a* concentrations and temperature

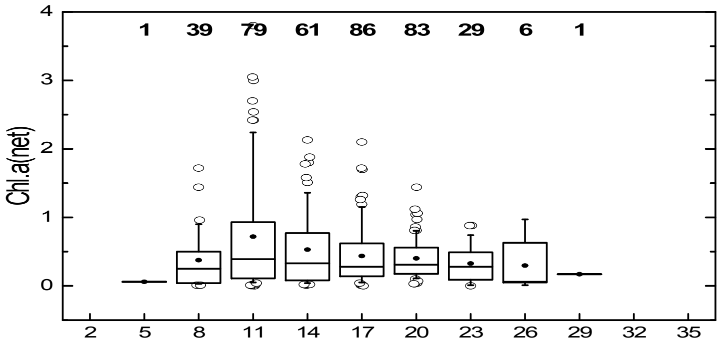
The total concentration of chlorophyll *a* in Hanul area has range of 0.02 ~ 5.27 ug L^{-1} which is less than Hanbit area. When the concentration of chlorophyll *a* was plotted as function of water temperature, data from Hanbit showed net peak values at 11℃ and 26-29℃ and similar trend was found in data from Hanul. Data from Hanul showed total peak values at 11℃ and 17℃. The main contributor was net plankton for 11℃ peak and nano plankton for 17℃ peak (fig. 2-20).

The annual(1999~2009), seasonal variations of phytoplankton growth inhibition ratio, calculated from changes in concentration of chlorophyll *a* at the intake and front discharge, are shown in table 2-7. The annual mean inhibition ratio was lowest in 2005 and highest in 2003.

(a)



(b)



(c)

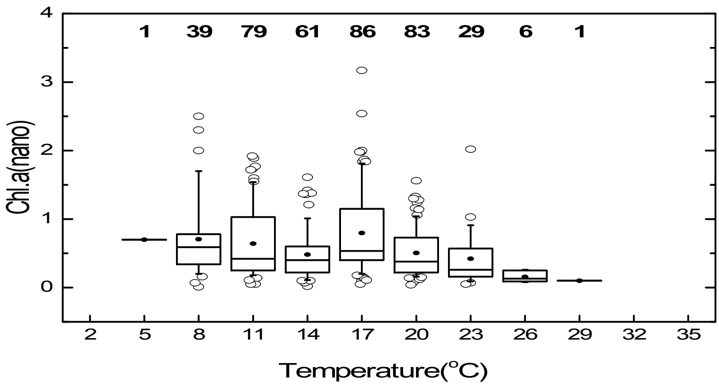


Fig. 2-20. Variation of chlorophyll *a* concentrations vs. temperature in Hanul area (a) total, (b) net, (c) nano chl. *a* concentrations vs. temperature; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

Table 2-7. Phytoplankton growth inhibition ratio(%) of Hanul NPP cooling systems (quoted from KHNP data)

season / year	winter	spring	summer	autumn	mean
1999	78.2	31.5	75.7	71.5	64.2
2000	62.8	74.7	49.0	44.2	57.7
2001	33.9	71.8	41.2	48.4	48.8
2002	46.2	63.6	43.9	50.7	51.1
2003	72.1	85.8	44.0	78.3	70.1
2004	52.4	-18.0	66.1	93.2	48.4
2005	55.8	50.8	-8.7	81.2	44.8
2006	37.7	82.6	85.0	50.0	63.8
2007	55.6	76.2	73.2	70.4	68.9
2008	52.0	74.0	80.3	68.7	68.7
2009	50.0	60.0	43.9	73.9	57.0
mean	54.2	59.4	54.0	66.4	58.5

Variation of phytoplankton major dominants and temperature

The medium term variations in the biomass and abundance of dominant species during 11 year period from 1999 to 2009 at Hanul site were shown in Appendix Table A-2. Each species of plankton may appear at different time, but when data are rearranged according to temperature, the results are shown in Fig. 2-21. For both Hanbit and Hanul, Diatom decreases in with increase in temperature and Dinoflagellate increases with increase in temperature.

Dominant species appeared at various temperatures were as follows. In general, Bacillaiophyceae and Dinophyceae were the two dominant taxa, while Dictyochophyceae and Euglenophyceae showed low biomass(Fig. 2-21). Bacillaiophyceae was dominant at low temperatures and Dinophyceae was dominant at high temperatures(Fig. 2-21 (a), (b)). *Leptocylindrus* spp. showed high abundance around 13-15℃. *Paralia sulcata* showed high abundance in Hanul area around 17-22℃. *Thalassiosira* spp. showed high abundance around 10-15℃. *Cheatoceros* spp.(inclding *C. curvisetus, C. danicus, D. debilis* and others) showed high abundance at 10℃ and around 20-25℃. The biomass of *Eucampia* spp. increased with temperature. *Prorocentrum micans* and *Prorocentrum minimum* which are Dinoflagellates also showed high abundance around 10-15 ℃. *Ceratium* spp. which is Dinoflagellate also showed high abundance at above 20℃.

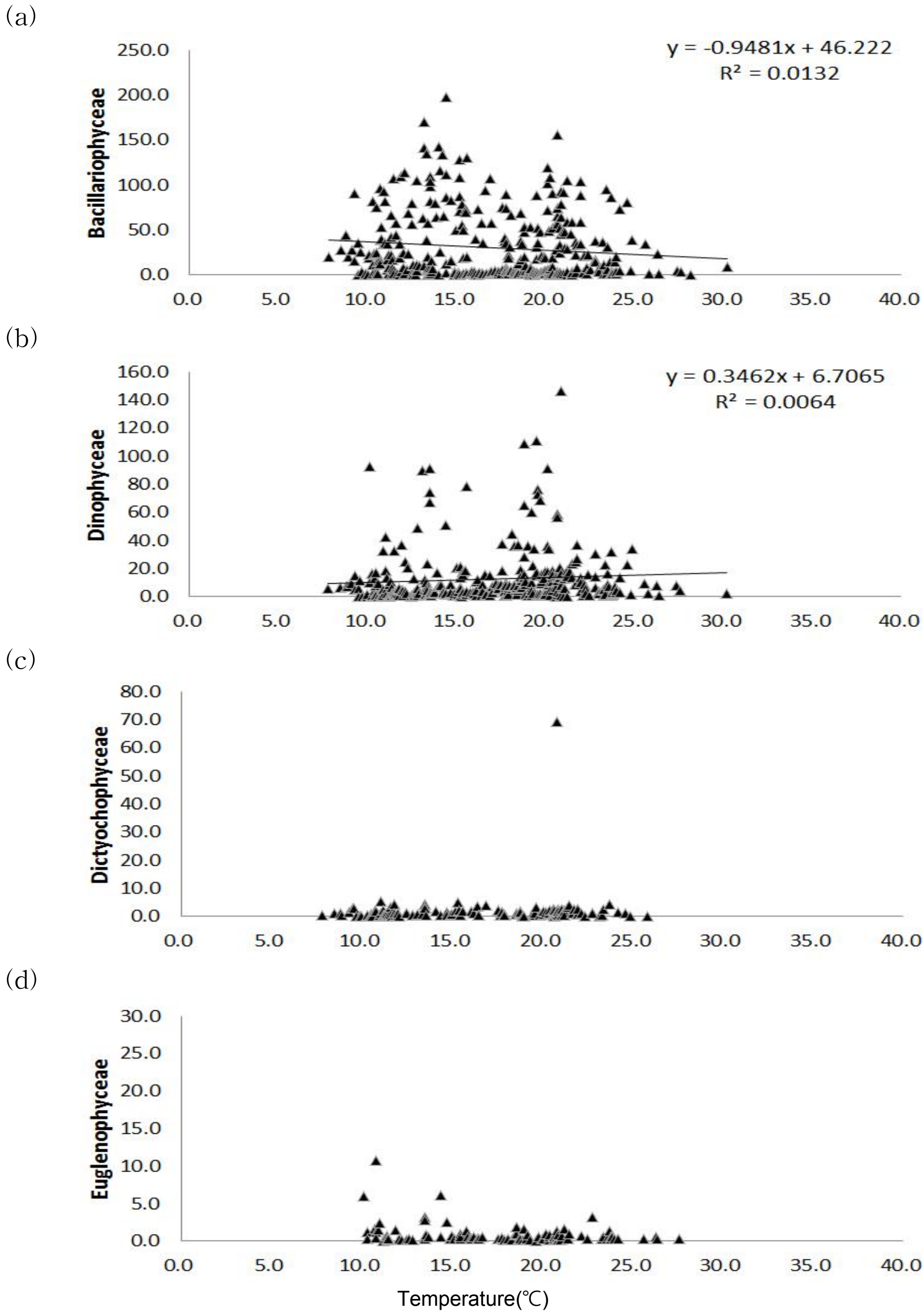
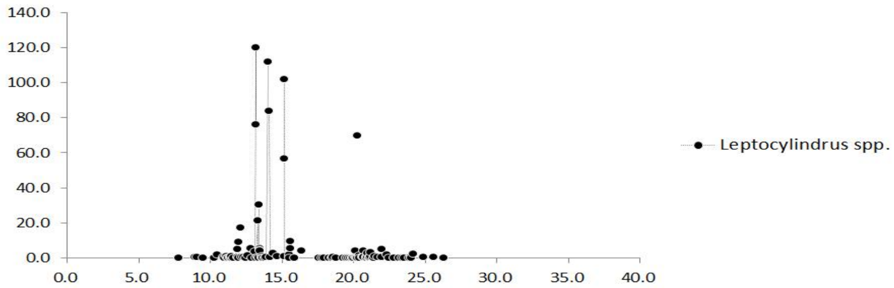
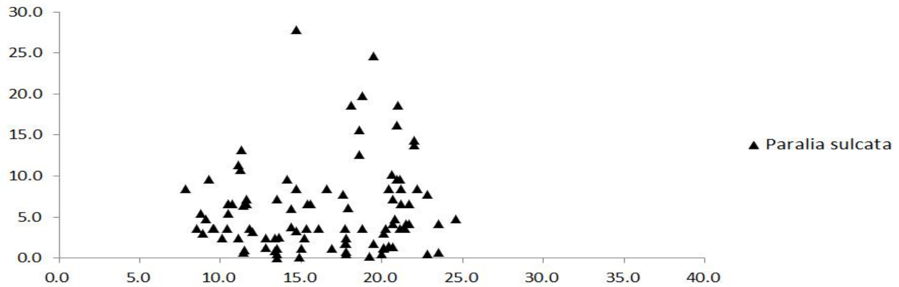


Fig. 2-21. Changes in biomass as function of temperature for Hanul site (a) Bacillariophyceae, (b) Dinophyceae, (c) Dictyochophyceae and (d) Euglenophyceae (y axis unit : n C mL^{-1}) (quoted from KHNP raw data)

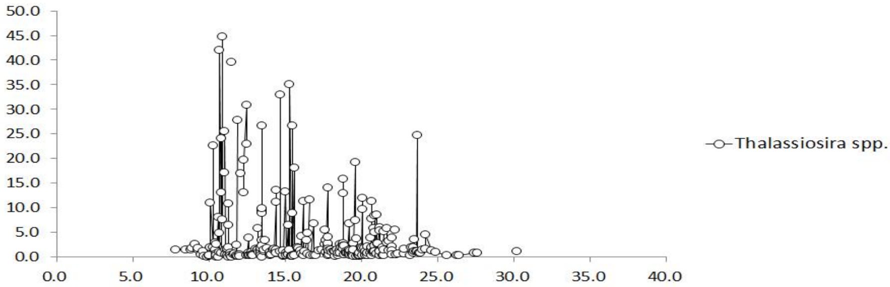
(e)



(f)



(g)



(h)

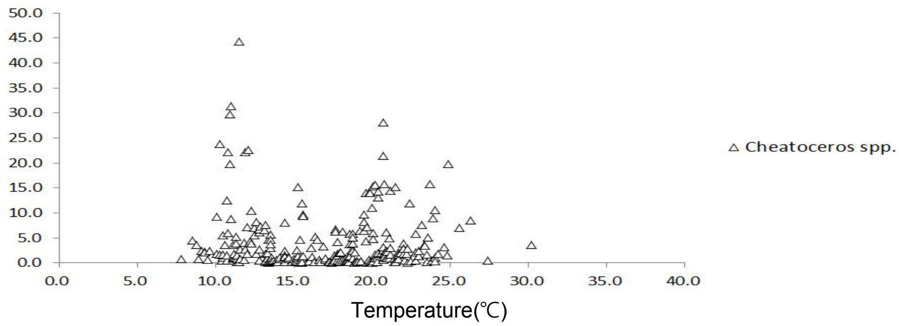
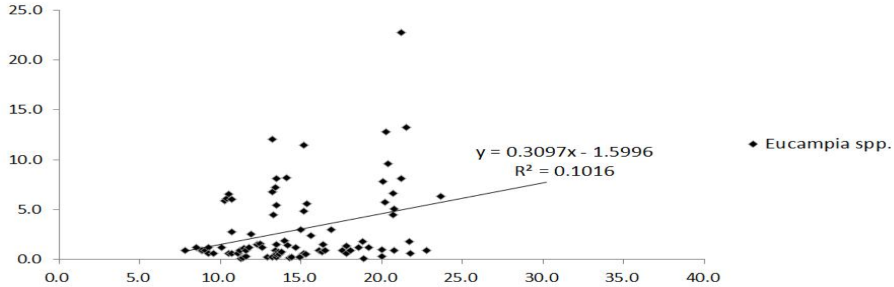
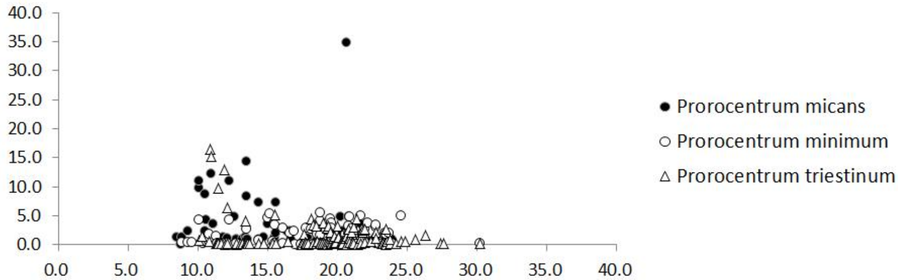


Fig. 2-21(cont.). Changes in biomass as function of temperature for Hanul site (e) *Leptocylindrus* spp.(●), (f) *Paralia sulcata*(▲), (g) *Thalassiosira* spp(○) and (h) *Chetoceros* spp. (△) (y axis unit : n C mL^{-1}) (quoted from KHNP raw data)

(i)



(j)



(k)

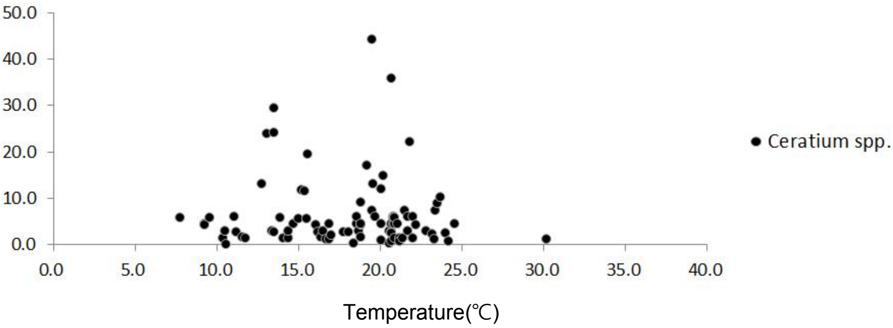


Fig. 2-21(cont.). Changes in biomass as function of temperature for Hanul site (i) *Eucampia* spp.(◆), (j) *Prorocentrum micans*(●), *P. minimum*(○), *P. triestinum*(△) and (k) *Ceratium* spp. (●) (y axis unit : n C mL^{-1}) (quoted from KHNP raw data)

2-4. Discussion

2-4-1. Hanbit site, west coast

Comparison of physicochemical properties

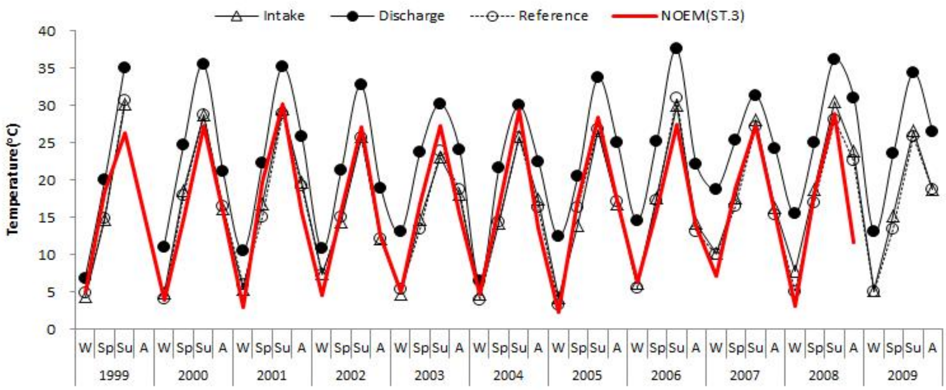
To get more accurate assessment of midium term environment changes in Hanbit power plant area, additional data from the National Ocean Environmental Measurement System(NOEMS) were obtained and compared with data from this study(Fig. 2-22). The NOEMS sites near Hanbit power plant are Gochang #3 and Gochang #4 on west coast. From site #3, which is located near Hanbit power plant, seasonal data(Feb. May, Aug. Nov.) from 1999 to 2008 were obtained. From site #4, east of Chilseondo, which is near the reference station in this study, data from 2000 to 2008 were obtained. The comparison of physicochemical properties between NOEMS data and data from the Hanbit area from this study showed that except discharge, seasonal changes in water temperature were similar. The water temperature is the initiating parameter to environment change in thermal discharge effluent.

Changes in pH and DO were generally similar with minor deviations between the two data. Ocean acidification is quantified by decreases in pH. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era, corresponding to a 26% increase in hydrogen ion concentration(IPCC, 2014). During the observation period, some seasonal or annual variations in pH was found, but no significant changes were found that would indicate medium term ocean acidification around Hanbit sites. But the magnitude of pH variation was increasing for Hanbit site for 2008~2009 and further monitoring is needed.

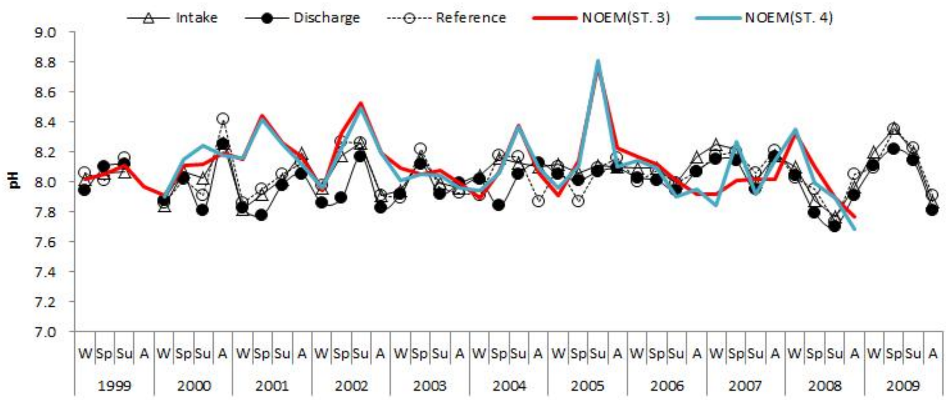
SS and SiO_2 showed relatively similar trend, but nutrients with nitrogen showed large differences between NOEMS data and data from this study. Further review of data is needed. Temperature, pH, and DO showed similar trend between NOEMS data and data from this study which fortifies the reliability of data used in this study.

In Hanbit area, DIN, SRP, and DSi did not show clear relationship with temperature. This seems to be due to large tidal range and strong tidal currents which are characteristics of West Sea with strong water mass turbulence.

(a)



(b)



(c)

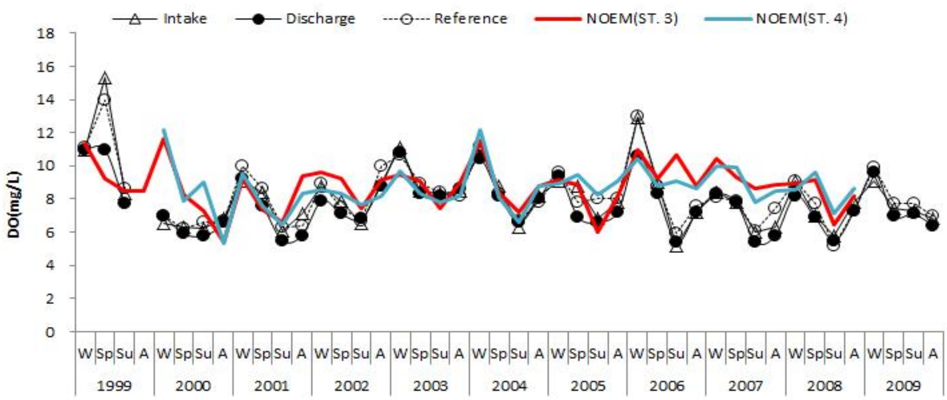
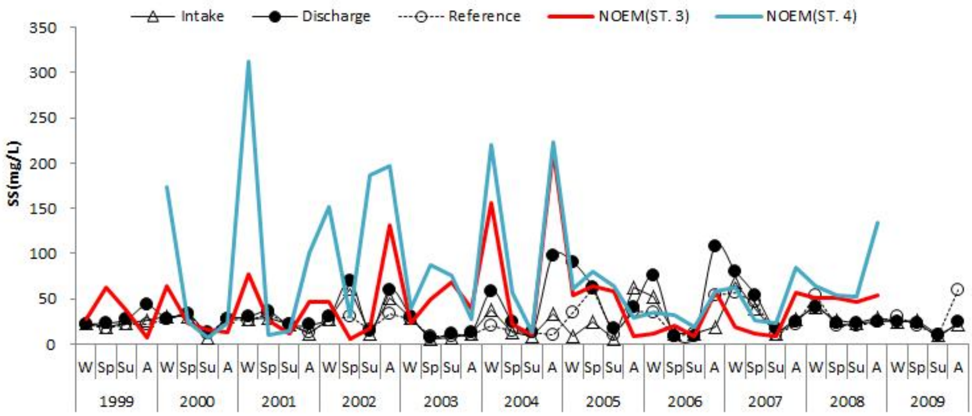


Fig. 2-22. Seasonal data comparison between NOEM and this results off the Hanbit NPP area from 1999 to 2009 (a) temperature(℃), (b) pH, (c) DO(mg L^{-1}) (quoted from KHNP and NOEM data)

(d)



(e)

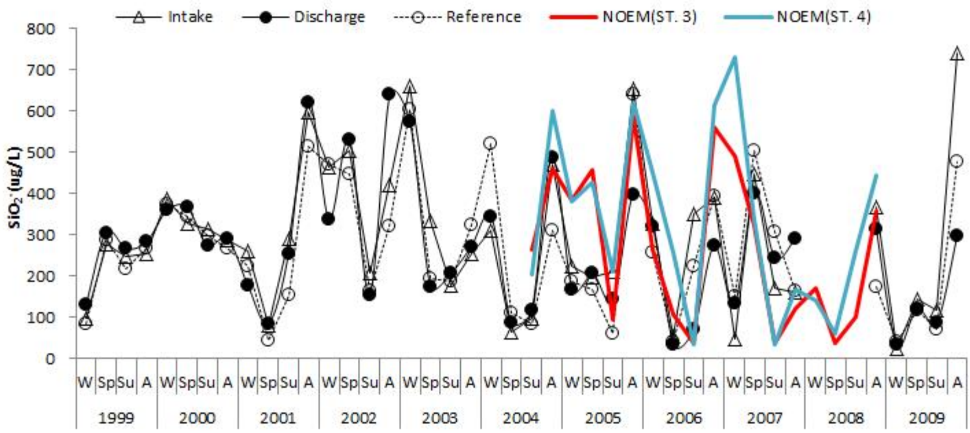
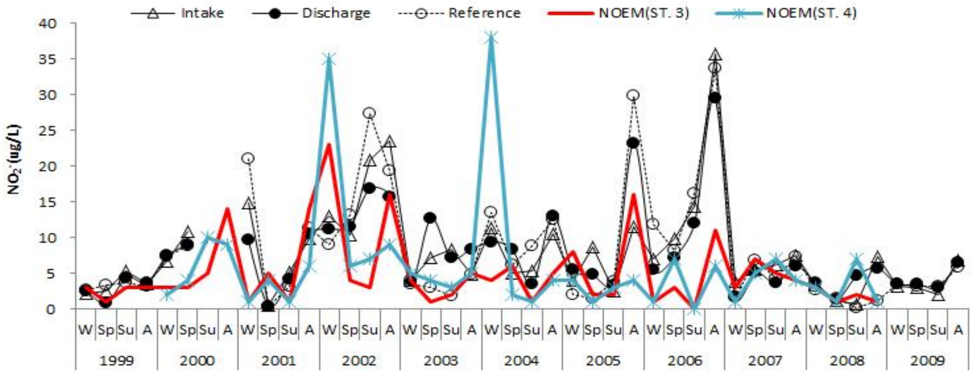


Fig. 2-22(cont.). Seasonal data comparison between NOEM and this results off the Hanbit NPP area from 1999 to 2009 (d) SS(mg L^{-1}), (e) SiO_2(ug L^{-1}) (quoted from KHNP and NOEM data)

(f)



(g)

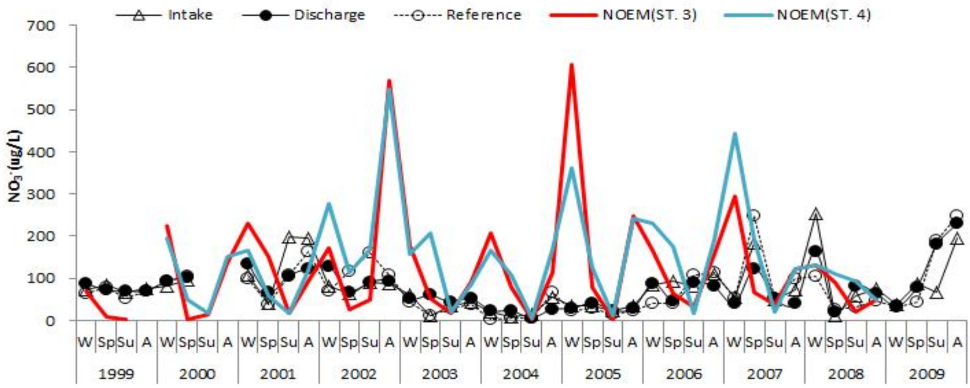


Fig. 2-22(cont.). Seasonal data comparison between NOEM and this results off the Hanbit NPP area from 1999 to 2009 (f) NO_2(ug L^{-1}), (g) NO_3(ug L^{-1}) (quoted from KHNP and NOEM data)

Comparison of abundance with season and station

Thermal discharge to the marine environment acts as external stress that can change the marine ecosystem. On a positive viewpoint, this thermal discharge can be considered as thermal enrichment. On a neutral viewpoint, this can be considered as thermal dispersion. On a negative viewpoint, this can be considered as thermal pollution, breaking balance of marine ecosystem (Moore, 1958). Based on observation that during winter season with low water temperature, the biomass at discharge station was higher than that at the intake station, and that as season changes from spring to autumn, the biomass at discharge station was noticeably lower than other stations, I can conclude that relatively warm discharge water from the nuclear power plant provides better environment for phytoplankton growth in winter.

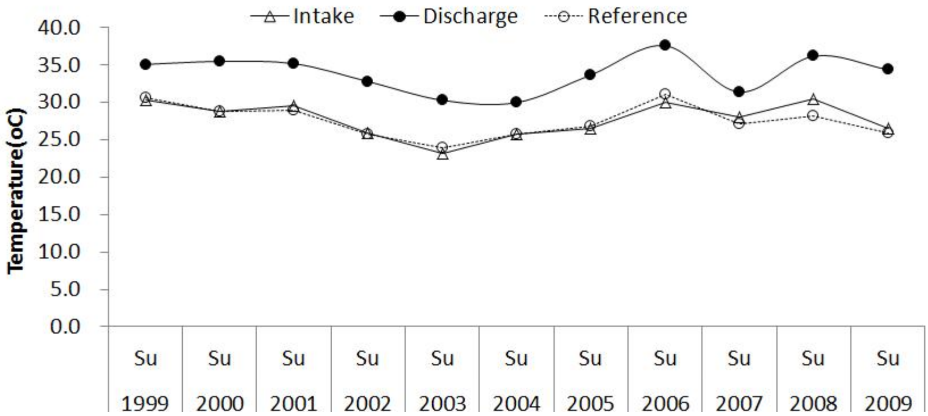
Data from the continuous plankton recorder survey in the northeast Atlantic have shown that rising sea surface temperature has increased phytoplankton abundance in cooler regions but decreased in warmer regions (Richardson & Schoeman, 2004). The seasonal variations near Hanbit area seems to be showing similar trend.

In Fig. 2-23, water temperature variation for summer and winter are shown separately. In summer, the temperature rise across the condenser is about 2.3~8.6℃ and in winter it is about 3.3~7.8℃.

In summer, the 11 year average temperature at discharge was 33.8℃ and since this was blooming season for *Eucampia zodiacus*, biomass was high (Appendix Table A-1). The biomass was 5,220.4 ng C mL^{-1} and dominance ratio was 51.0%. In winter, the temperature of discharge water provided suitable temperature range for phytoplankton. The 11 year average temperature at discharge for winter was 12.1℃ which was the same as Hanbit area blooming temperature in Fig. 2-9. From Appendix Table A-1, the *Thalassiosira decipiens* was dominant species with biomass of 570.4 ng C mL^{-1} and dominance ratio of 84.7%.

In seasons other than winter, exposure to relatively high temperature inside the condenser causes death of phytoplankton or further raising of water temperature in season with high sea water temperature may cause decrease in population of phytoplankton.

(a)



(b)

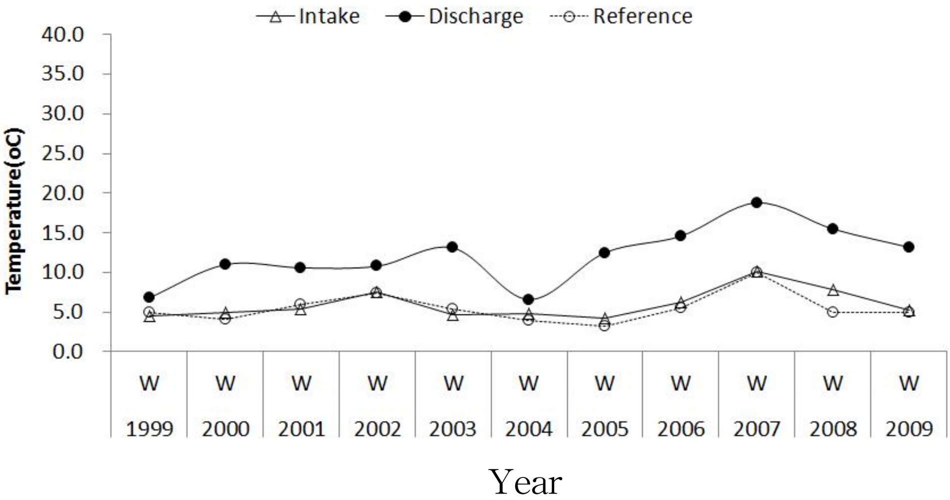


Fig. 2-23. Temperature variation of Hanbit area over 11 year period (a) summer, (b) winter (quoted from KHNP raw data)

Phytoplankton growth inhibition and temperature

Since chlorophyll *a* concentration is a good indicator of phytoplankton biomass or productivity, it is used in measuring phytoplankton growth inhibition in sea water running through the condenser of power plant cooling system.

The phytoplankton passing through the power plant cooling system are affected by thermal, chloride and mechanical shocks(Langford, 1990). However, they have great ability to recover from these shocks, the effect on the structure of total phytoplankton communities are small(Fox and Moyer, 1973; Bienfang and Johnson, 1980).

Fig. 2-24 shows growth inhibition ratio in Table 2-5 as a function of discharge temperature. The phytoplankton growth inhibition ratio increased with increase in discharge temperature for Hanbit site.

Although I can expect higher biomass without growth inhibition effect of entrainment to plant cooling system, it is not possible to separate the effect of discharge temperature and cooling system entrainment from data obtained from near NPP area. To see the separate effect of temperature increase, laboratory experiment with environment conditions matching the plant sites is needed.

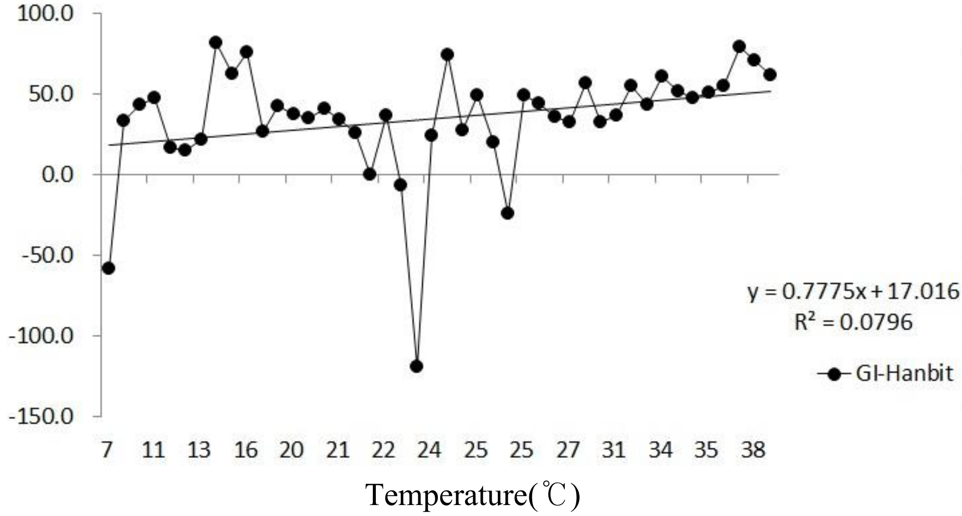


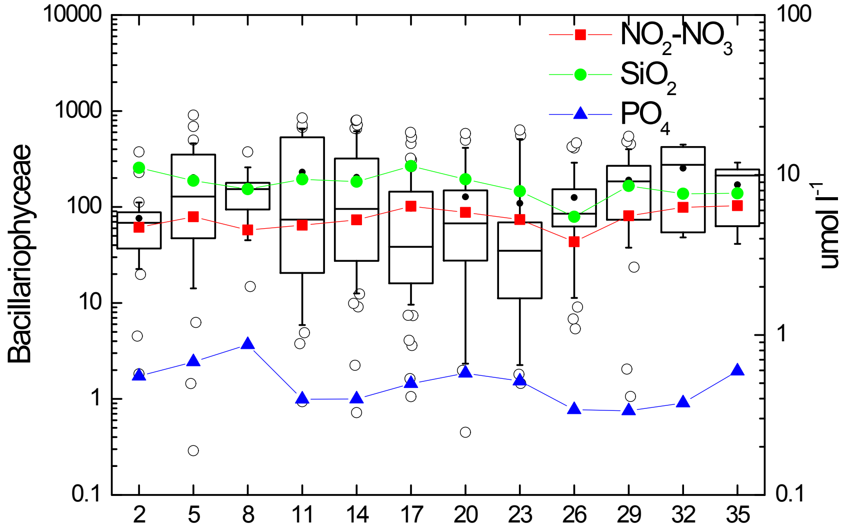
Fig. 2-24. Effect of cooling system entrainment on phytoplankton inhibition ratio as function of water temperature in Hanbit NPP (quoted from KHNP raw data)

Comparison of nutrient doncentrations and phytoplankton biomass

The relationship between DIN(NO_2+NO_3), DIP and DSi nutrients and phytoplankton biomass for Hanbit area are shown in Fig 2-25. DIN and DSi showed similar trend as phytoplankton growth, but DIP decreased when phytoplankton grew and DIP increased when the growth ended. Nutrients were important factor for phytoplankton growth, and DIP was the key factor for Hanbit NPP area. Previous study on phytoplankton and environment parameters near Kori, Wolsong, Hanul and Hanbit area from 1992 to 1996 also pointed out the importance of DIP at Hanbit area on phytoplankton growth(Kang, 2002). From these observations, I can conclude that in addition to temperature which is the most important factor for phytoplankton growth, nutrients also play an important role in phytoplankton growth.

Biomass showed negative correlation with DIP. Dinophyceae and Bacillariophyceae showed almost the same trend showing negative correlation with DIP.

(a)



(b)

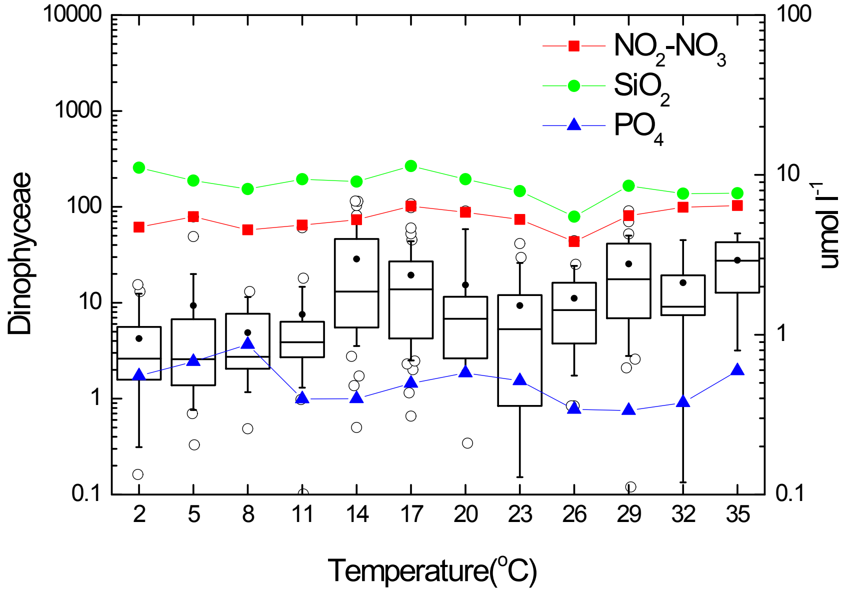


Fig. 2-25. Comparison of biomass for dominant taxon and nutrient concentrations at Hanbit site (a) Bacillariophyceae, (b) Dinophyceae; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

Correlation of phytoplankton biomass and environmental factors

The relationship between Hanbit's phytoplankton biomass and environment parameters were studied. Correlations between the biomass of phytoplankton taxa and physical and chemical properties near Hanbit plant area are shown in table 2-8. The results for Hanbit area show that biomass of total phytoplankton and Bacillariophyceae positively correlated with NO_2+NO_3. The biomass of Dinophyceae negatively correlated with PO_4 and positively correlated with water temperature. The biomass of Dictyochophyceae positively correlated with SiO_2 and SS. The biomass of Euglenophyceae positively correlated with PO_4 and SiO_2. The biomass of Chlorophyceae positively correlated with water temperature and negatively correlated with suspended solid.

Table 2-8. Correlations between the biomass of phytoplankton and physical and chemical properties in Hanbit area from 1999 to 2009 (quoted from KHNP raw data)

Components	T	Tr.	pH	DO	COD	SS	SiO_2	PO_4	NO_2+NO_3
PHYTO									.149**
DIA				.102*					.154**
DINO	.165**							-.166**	
DICTYO						.159**	.122*		
EUG							.131*	.187*	
CYANO									
CHL	.162*					-.138**			

PHYTO: total phytoplankton, DIA: bacillariophyceae, DINO: Dinophyceae, DICTYO: dictyochophyceae, EUG: euglenophyceae, CYANO: cyanophyceae, CHL: chlorophyceae, T: Temperature, Tr.: Transparency, DO: Dissolved oxygen, COD: Chemical oxygen demand, SS: Suspended solid, SiO_4: Silicate, PO_4: Phosphate, NO_2: Nitrite, NO_3: Nitrate.
$^{*}p<0.05$

2-4-2. Hanul site, the east coast

Comparison of physicochemical properties

Data from sites near the Hanul NPP was also compared with the data from NOEMS. The NOEMS sites near Hanul NPP are Jukbeun#1 and Jukbeun#2 on the east coast. From site #1, east of Buguri, seasonal data(February, May, August, November) from 1999 to 2008 were obtained. From site #2, which is near Hanul power plant, data from 2000 to 2008 were obtained.

The comparison of water temperature between NOEMS data and data from the Hanul area from this study showed that except discharge, seasonal changes in water temperature were similar in both data. Changes in pH and DO were generally similar with minor deviations between two data. SiO_2 and NO_2 showed relatively similar trend, especially SiO_2 data from 2006~2008 and NO_2 peak of 2001. But nitrogen showed large differences between NOEMS data and data from this study. Further review of data is needed. Data that does not require chemical analysis such as temperature, pH, DO, showed similar trend between NOEMS data and data from this study (Fig. 2-26).

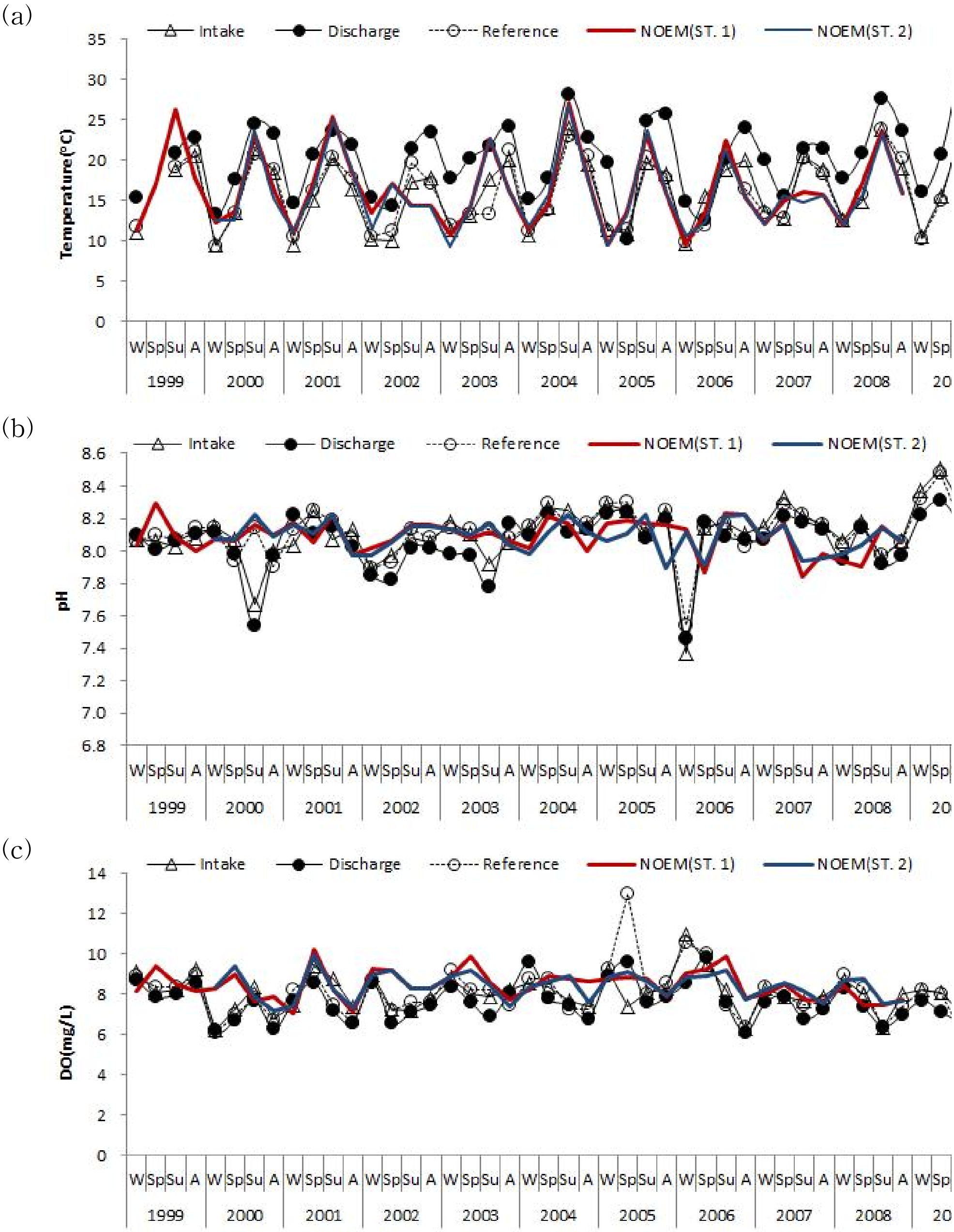
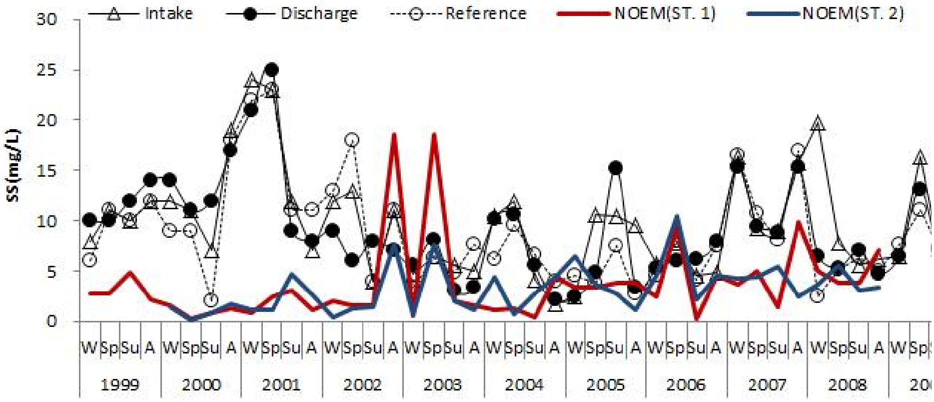


Fig. 2-26. Seasonal data comparison between NOEM and this results off the Hanul NPP area from 1999 to 2009 (a) temperature(℃), (b) pH, (c) DO(mg L^{-1}) (quoted from KHNP and NOEM data)

(d)



(e)

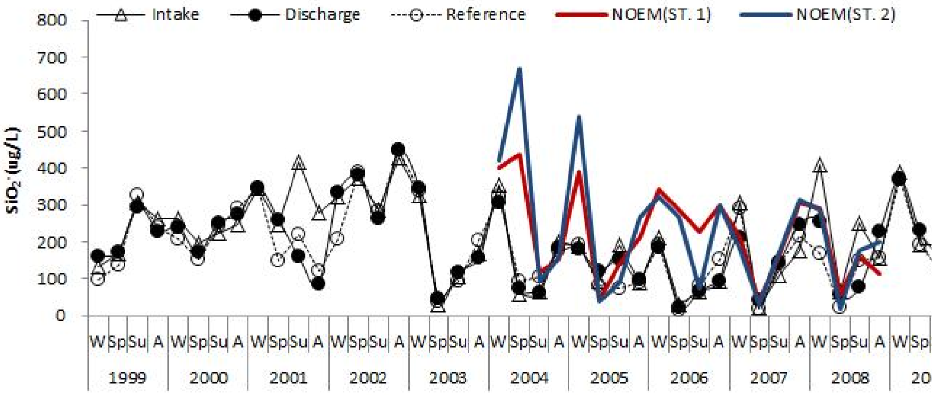
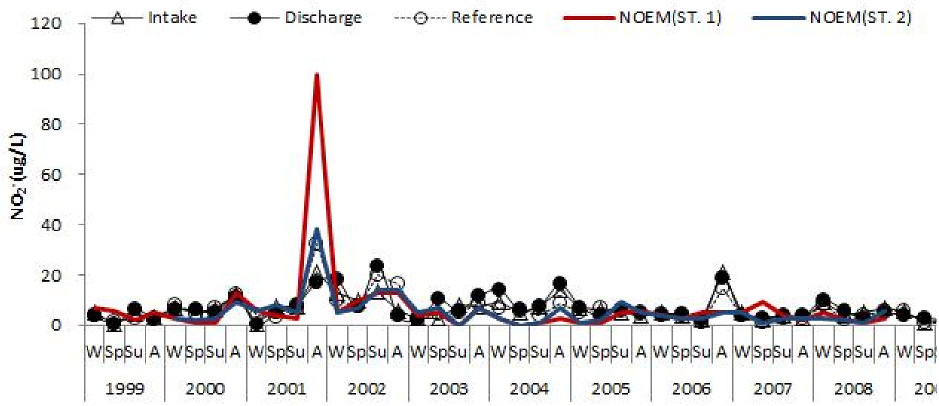


Fig. 2-26(cont.). Seasonal data comparison between NOEM and this results off the Hanul NPP area from 1999 to 2009 (d) SS(mg L^{-1}), (e) SiO_2(ug L^{-1}) (quoted from KHNP and NOEM data)

(f)



(g)

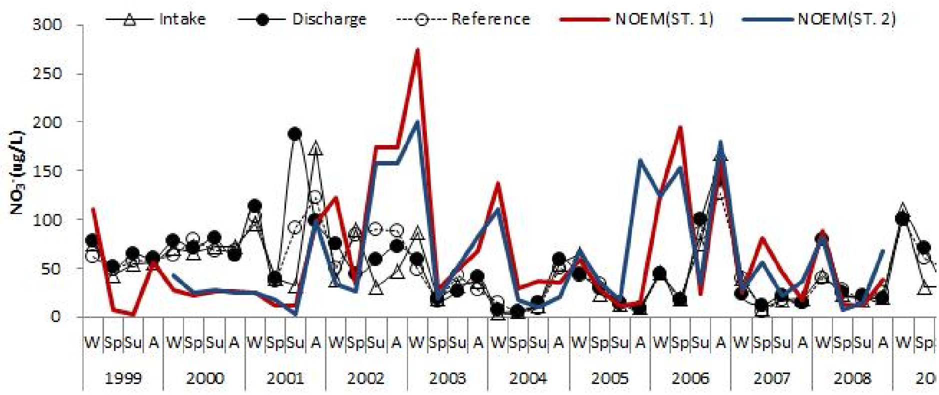


Fig. 2-26(cont.). Seasonal data comparison between NOEM and this results off the Hanul NPP area from 1999 to 2009 (f) NO_2(ug L^{-1}), (g) NO_3(ug L^{-1}) (quoted from KHNP and NOEM data)

Comparison of abundance with season and station

When the abundance of total phytoplankton for each season near Hanbit NPP were compared, relationship of winter < autumn < summer < spring was found. Also, other than in winter, the abundance at the discharge station was definitely lower than intake or reference station. However, when based on the amount of carbon, the biomass in seasons other than winter were similar. Also carbon based biomass was certainly lower in discharge station than intake or reference station in summer and autumn(especially in autumn). Generally, the comparison of abundance showed differences between stations more clearly than comparison of biomass.

Same trend was found in diatoms, which accounted for the largest portion of phytoplankton. The Dinophyceae also showed lower abundance at discharge station than intake or reference station in spring and summer. The abundances of other taxa were too low to find such a trend.

In Fig. 2-27, water temperature variation of Hanul area for summer and winter are shown separately. In summer, the temperature rise across the condenser is about 0.9~7.0℃ and in winter about 3.8~8.2℃. In summer, the 11 year average temperature was 20.5℃, which corresponds with *Thalassiosira* genus blooming season in Appendix Table A-2. Other dominant species were Dinophyceae, such as *Alexandrium tamarensis, Protoperidinium pellagicum, Ceratium tripos, Dinophysis forthii, etc.* In winter, the temperature of discharge water provided suitable temperature range for phytoplankton. The 11 year average temperature at discharge for winter was 16.4℃ which is the same as Hanul area blooming temperature in Fig. 2-19 (d).

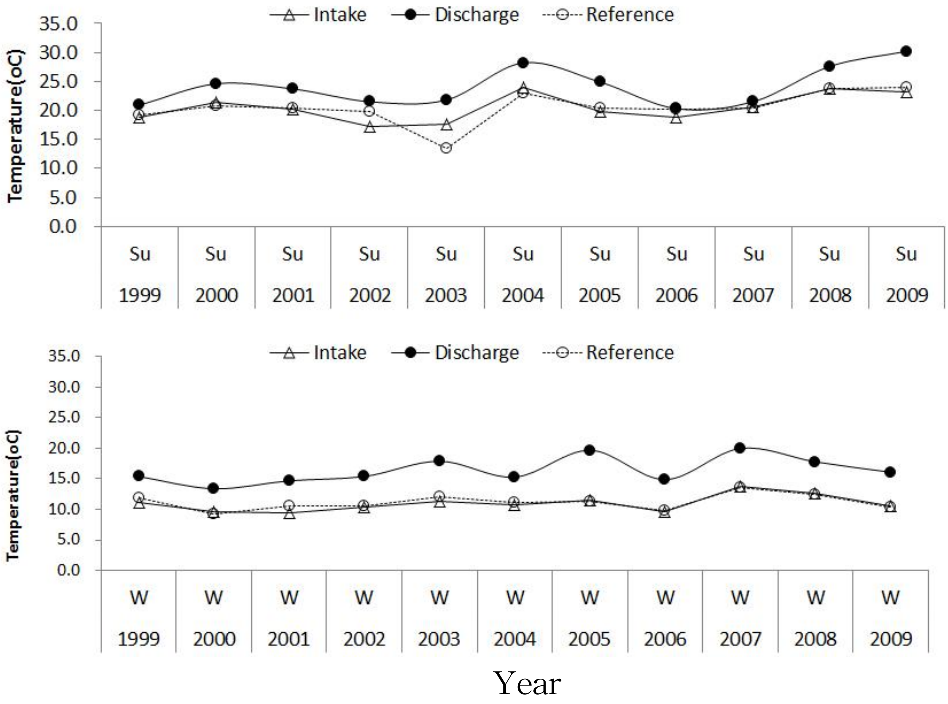


Fig. 2-27. Temperature variation of Hanul area over 11 year period (a) summer, (b) winter (quoted from KHNP raw data)

Phytoplankton growth inhibition and temperature

Fig. 2-28 shows growth inhibition ratio in Table 2-7 as a function of discharge temperature. The phytoplankton growth inhibition ratio remained constant even if discharge temperature increased for Hanul site. When temperature ranges common to both sites(below 30℃) were chosen, both Hanbit and Hanul sites showed that growth inhibition ratio did not change much with water temperature. For Hanul site, the effect of mechanical shocks and chloride shocks were more important than thermal shocks and effect of growth inhibition remained nearly constant.

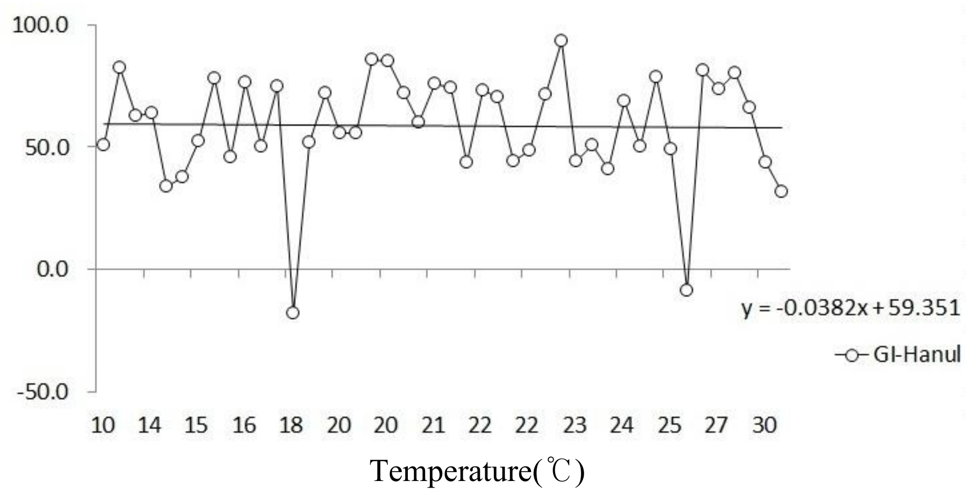


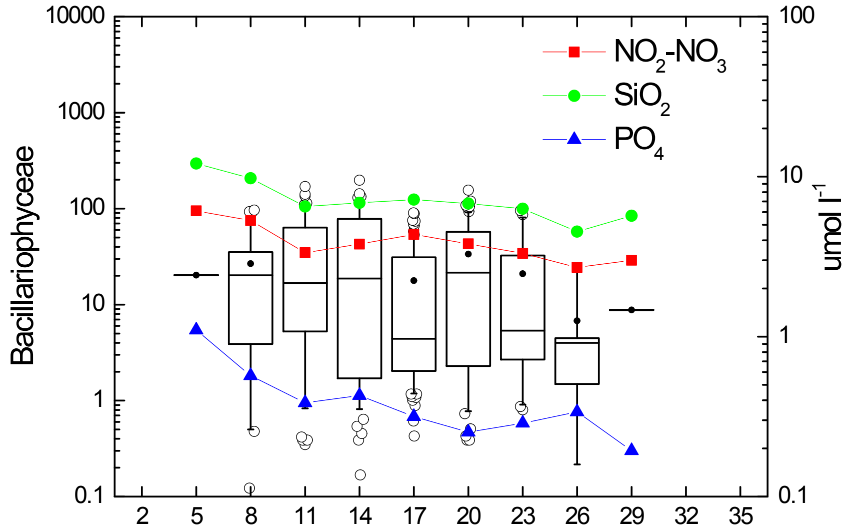
Fig. 2-28. Effect of cooling system entrainment on phytoplankton inhibition ratio as function of water temperature in Hanul NPP (quoted from KHNP raw data)

comparison of nutrient concentrations and phytoplankton biomass

Nutrients are important factor for phytoplankton growth, and DIP is the key factor for Hanul NPP area like Hanbit case. Previous study on phytoplankton and environment parameters also pointed out the importance of DIP at Hanbit and Hanul area on phytoplankton growth(Kang, 2002).

Also, biomass showed negative correlation with DIP for Hanbit and Hanul sites. Bacillariophyceae and Dinophyceae showed similar trend having negative correlation with DIP.

(a)



(b)

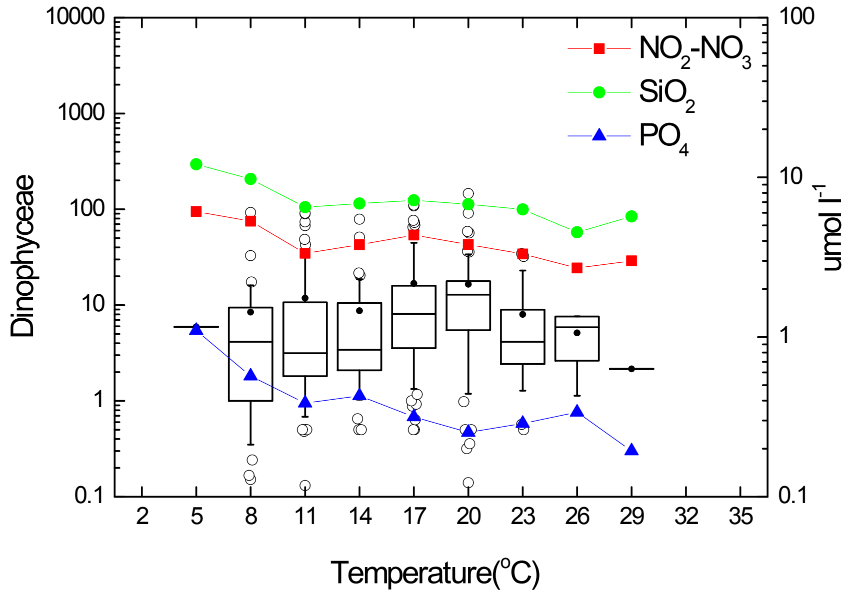


Fig. 2-29. Comparison of biomass for dominant taxon and nutrient concentrations at Hanul site (a) Bacillariophyceae, (b) Dinophyceae; see Fig. 2-8 for box plot information (quoted from KHNP raw data)

Correlation of phytoplankton biomass and environmental factors

The relationship between Hanul's phytoplankton biomass and environment parameters were studied. Correlations between the biomass of phytoplankton and physical and chemical properties in 9 sites near Hanul plant area are shown in Table 2-9. The results for Hanul plant area showed that biomass of total phytoplankton and Bacillariophyceae were negatively correlated with transparency and positively correlated with suspended solid. The biomass of Dinophyceae was positively correlated with transparency but the level of confidence was not high.

Table 2-9. Correlations between the biomass of phytoplankton and physical and chemical properties in Hanul area from 1999 to 2009 (quoted from KHNP raw data)

Components	T	Tr.	pH	DO	COD	SS	SiO_2	PO_4	NO_2+NO_3
PHYTO		-.245**				.205**			
DIA		-.234**				.206**			
DINO		-.187**	-.163**			.127*			
DICTYO									
EUG									
CYANO	-.126*			-.202**		.109*			.103*
CHL									

PHYTO: total phytoplankton, DIA: bacillariophyceae, DINO: Dinophyceae, DICTYO: dictyochophyceae, EUG: euglenophyceae, CYANO: cyanophyceae, CHL: chlorophyceae, T: Temperature, Tr.: Transparency, DO: Dissolved oxygen, COD: Chemical oxygen demand, SS: Suspended solid, SiO_4: Silicate, PO_4: Phosphate, NO_2: Nitrite, NO_3: Nitrate.
*$p<0.05$

2-4-3. Summarizing discussion on Hanbit and Hanul site field experiment data

Previous study reported negative correlation with temperature for Bacillariophyceae biomass, and positive correlation with temperature for Dinophyceae biomass(Xie et al, 2015). However, the western English Channel, which was used as sampling station for the previous study, had smaller temperature variation (7.3~18.2℃) than current study and this smaller temperature variation resulted in linear relationship with temperature. In current study, the biomass change was not linear, seemingly due to wider temperature range than the reference. In Hanul area, Dinophyceae biomass showed decreasing trend after a peak at 20℃. However in Hanbit area, the biomass decreased after a peak at 14℃, then increased again after 23℃ (Fig. 2-9 (d), 2-19 (d)). In general, Dinophyceae tended to increase slightly with temperature rise (Fig. 2-11 (b), 2-21 (b)).

dominant species were listed for each observed temperature. *Paralia sulcata* was found to be top dominant species for Hanbit area. *Paralia sulcata* was typical tychopelagic species found in West Sea after vertical mixing(Choi and Shim, 1986).

Comparison of the changes in environment and plankton communities around Hanbit and Hanul area

The Hanbit and Hanul NPP sites represent west and east coastal area of Korea. Medium term changes in reference site of each power plant were compared to assess medium term changes in coastal environment and ecosystem of Korea.

In terms of water temperature, Hanbit NPP area showed higher seasonal variation than Hanul NPP area. In winter, the average temperature was 5.5 ℃ in Hanbit area and 11.2℃ in Hanul area. In summer, the average temperature was 27.5℃ in Hanbit area and 20.5℃ in Hanul area. This was a result of characteristics of east and west coast. The west coast is shallow and has large tidal range. The east coast is deep and warm currents crosses depending on the season.

The Hanbit NPP area also shows higher seasonal variation of transparency and suspended solids than Hanul NPP area. It also reflects shallow water depth, strong currents, and fine-grained sediments of west coast of Korea.

The pH and DO did not show site dependency. Instead, they showed seasonal variations. Nutrients such as SiO_2 and NO_2 did not show clear trends. But, in general, the Hanbit NPP area showed larger variation than Hanul area.

In terms of biomass of total phytoplankton, the Hanbit NPP area showed higher value than Hanul area. The same trend was found in biomass of Bacillariophyceae, which is the dominant taxon. One exception to this trend was biomass of Dinophyceae, where two site showed similar value and sometimes Hanul area had higher value. The amount of Dinophyceae made up higher percentage of phytoplankton in the Hanul area than Hanbit area.

For Hanbit site, discharge temperature above 30℃ was observed. This suggests that for Hanbit site, the phytoplankton was subjected to thermal shock when passing through the condenser while for Hanul site, the effect of mechanical shocks and chloride shocks were more important than thermal shocks and effect of growth inhibition remained nearly constant.

Prediction of effects of temperature elevation on phytoplankton communities in coastal waters

The effect of thermal condenser effluent from nuclear power plant were studied by observing changes in biomass with temperature, with additional consideration of other parameters such as physical, chemical and biological components. Appearance of certain species with changes in water temperature were also studied.

From various observations, further global warming in the future will likely to result in following changes.

1. Increase in water temperature will result in increased fraction of dinoflagellates in the total phytoplankton communities.

2. Increase in water temperature will result in higher increase of eurythermal and high temperature adapted plankton rather than low temperature adapted plankton.

3. Increase in water temperature will make other parameters such as concentration of nutrients become more important.

2-5. Conclusion

From review of various data, I can find several conclusions as follows:

1. Between 1999 to 2009, temperature varied from 2.4 to 37.6℃ in Hanbit area and from 7.8 to 30.2℃ in Hanul area. The temperature difference between discharge station and intake station change due to power plant operation and warm water discharge were about 1.8~9.0 ℃ for Hanbit area and 0.9~8.8 ℃ for Hanul area.

2. Other than temperature change, there was no other noticeable change in marine environmental conditions. To find if there are any environment parameters other than temperature affected by the power plant, comparison was made to environment beyond the power plant affected area using data from National Ocean Environmental Measurement System(NOEMS). The result of comparison showed that there are no evidence of physicochemical change near power plant other than temperature increase due to condenser effluent.

3. In this study, phytoplankton abundances at the Hanbit NPP discharge area was higher than those of intake and reference sites in winter season. In other seasons the phytoplankton abundance at discharge was lower than other sites. This indicates during spring~autumn season, growth inhibition effect of thermal discharge effluent was more dominant, while in winter, elevation of water temperature contributed to higher growth rate of phytoplankton.

4. In Hanul NPP area, the phytoplankton biomass at 9 sites did not show much difference. This result was different from Hanbit NPP. For Hanul NPP, the warm condenser effluent did not seem to affect phytoplankton

community.

5. In both sites, the changes in total phytoplankton coincided with changes of Bacillariophyceae, which was the dominant species. Biomass peaks for Bacillariophyceae were observed at 11℃ and 32℃ for Hanbit and 14℃ and 20℃ for Hanul. However, peaks for Dinophyceae were observed at higher temperatures than Bacillariophyceae with peaks at 14℃, 29℃ and 35℃ for Hanbit. For Hanul, the biomass of Dinophyceae increased from 14℃ to 20℃ and decreased above 20℃.

6. The phytoplankton growth inhibition due to cooling system entrainment were 34.5% for Hanbit and 58.5% for Hanul, averaged over 11 year period. Although the cooling system entrainment was found to be one of the reasons for biomass not increasing proportionally to temperature, it was not possible to distinguish the effect of thermal shocks and mechanical shocks from growth inhibition data with discharge temperature below 30℃. The increase in growth inhibition with temperature at discharge temperature above 30℃ observed in Hanbit area indicated effect of thermal shocks.

7. In addition to water temperature, nutrients concentrations were important factors for phytoplankton biomass near nuclear power plants. Especially for Hanbit area, the abundance of Bacillariophyceae and Dinophyceae showed weak negative correlation with DIP.

8. Despite having similar generating capacity and similar thermal condenser effluent flow rate, Hanbit NPP discharging to west coast showed different effect on marine ecology compared with Hanul NPP discharging to east coast due to differences in marine environment.

9. In summary, through this study, changes in environmental conditions due to thermal condenser effluent from nuclear power plant were reviewed quantitatively. Comparison of data measurement from 9 stations, changes in environmental conditions generally had effect on phytoplankton community. Under certain circumstances, such as Hanbit NPP area during winter season, warm condenser effluent might contribute to increase of phytoplankton. Warm condenser effluent alone was not the deciding factor for the phytoplankton communities.

10. By studying the effect of thermal condenser effluent to near by marine ecosystem, a better assessment of the effect of future global warming and climate change on marine ecosystem could be made. Increase in water temperature would result in increased fraction of dinoflagellates in the total phytoplankton communities. Increase in water temperature would result in higher increase of eurythermal and high temperature adapted plankton rather than low temperature adapted plankton. Increase in water temperature would make other parameters such as concentration of nutrients become more important.

Chapter 3. Mixotrophic Ecological of a newly described dinoflagellate species, *Ansanella granifera*

3-1. Introduction

Phototrophic dinoflagellates are one of the major components in marine planktonic communities (Smayda 1997, Jeong et al. 2013a, 2013b, Park et al. 2013a). For a long time, these dinoflagellates were treated as phytoplankton, which can survive only by photosynthesis. However, in the last 2 decades, tens of phototrophic dinoflagellates have been revealed to be mixotrophic (Stoecker 1999, Jeong et al. 2005c, 2010b, 2012, Turner 2006, Burkholder et al. 2008, Kang et al. 2011); they are known to feed on diverse prey, such as heterotrophic bacteria, cyanobacteria, small flagellates, other mixotrophic dinoflagellates, and ciliates (Stoecker et al. 1997, Jeong et al. 1999, 2005b, 2005c, 2005d, 2010a, 2012, Li et al. 1999, Park et al. 2006, Seong et al. 2006, Berge et al. 2008a, 2008b, Glibert et al. 2009, Yoo et al. 2009, Kang et al. 2011). Thus, discovery of mixotrophy in phototrophic dinoflagellates increase the complexity in food webs, but help in better understanding predator-prey relationships and cycling of materials in the food webs (Jeong et al. 2010b). Some mixotrophic dinoflagellates sometimes have considerable grazing impact on populations of prey species (Jeong et al. 2005c). Recently, several new genera and/or species of phototrophic dinoflagellates have been established (Moestrup et al. 2008, 2009a, 2009b, Kang et al. 2010, Jeong et al. 2014b). To understand the eco-physiology of a phototrophic dinoflagellate and its roles in planktonic food webs of the ecosystem, the feeding ability, type of prey, feeding mechanisms, growth and ingestion rates of this phototrophic dinoflagellate need to be explored.

Recently, I found a new mixotrophic dinoflagellate *Ansanella granifera* in

Shiwha Bay, Korea (Jeong et al. 2014a). This newly isolated, thin-walled dinoflagellate has a type E eyespot and a single elongated apical vesicle, and it is closely related to species belonging to the family Suessiaceae. *Ansanella granifera* has 10-14 horizontal rows of amphiesmal vesicles, comparable to *Biecheleria* spp. and *Biecheleriopsis adriatica*, but greater in number than in other species of the family Suessiaceae (Montresor et al. 1999, Kremp et al. 2005, Moestrup et al. 2009a, 2009b, Siano et al. 2009, 2010, Kang et al. 2011, Luo et al. 2013, Takahashi et al. 2014, Jeong et al. 2014a, 2014b). Unlike *Biecheleria* spp. and *B. adriatica, A. granifera* has grana-like thylakoids (Horiguchi and Pienaar 1994a, 1994b, Moestrup et al. 2009a, 2009b, Jeong et al. 2014a). Further, *A. granifera* lacks a nuclear fibrous connective, which is present in *B. adriatica* (Moestrup et al. 2009b, Jeong et al. 2014a). *B. adriatica* and *A. granifera* also show a morphological difference in the shape of the margin of the cingulum. In *A. granifera*, the cingular margin formed a zigzag line, and in *B. adriatica* a straight line, especially on the dorsal side of the cell (Moestrup et al. 2009b, Jeong et al. 2014a, Takahashi et al. 2014). The main accessory pigment is peridinin. The small subunit (SSU), internal transcribed spacer regions, and large subunit (LSU) rDNA sequences differ considerably from those of the other known genera in the order Suessiales. *A. granifera* has a 51-base pair fragment in domain D2 of the LSU of ribosomal RNA, which is absent in the genus *Biecheleria*. In the phylogenetic tree based on the SSU and LSU sequences, *A. granifera* belongs to the large clade of the family Suessiaceae, but a small clade containing this dinoflagellate is clearly divergent from other small clades in the family (Jeong et al. 2014a).

I established a clonal culture of *A. granifera* and observed its feeding behavior under high-resolution video-microscopy in order to explore the feeding mechanisms and determine the prey species when diverse algal species were provided. I also conducted experiments to determine the effects of prey concentration on the growth and ingestion rates of *A. granifera* feeding on the prasinophyte *Pyramimonas* sp., the only algal prey, as a function of prey concentration. In addition, I estimated the grazing coefficients attributable to *A. granifera* feeding on *Pyramimonas* sp. using the ingestion rate obtained from the laboratory experiments and the abundances of predators and prey in the field. The abundances of *A. granifera* and *Pyramimonas* sp. were quantified using real-time polymerase chain reaction (PCR). The results of the present study provide a basis for understanding the feeding mechanisms and ecological roles of *A. granifera* in marine planktonic food webs.

3-2. Materials and methods

Preparation of the experimental organisms

The phytoplankton species were grown at 20°C in enriched f/2 seawater media under an illumination of 20 μE $m^{-2}s^{-1}$ of cool white fluorescent light on a 14 : 10 h light-dark cycle. The mean equivalent spherical diameter (ESD) ± standard deviation was measured by using an electronic particle counter (Coulter Multisizer II; Coulter Corporation, Miami, FL, USA). *Synechococcus* sp. (Genbank accession Nos. DQ023295; ESD = ca. 1 μm) were grown at 20°C and 30-31 salinity in enriched f/2 seawater media under a 14 : 10 h light-dark cycle with 20 μE $m^{-2}s^{-1}$ of cool white fluorescent light. The heterotrophic bacterial cells that originated from a clonal culture of *A. granifera* were fluorescently labeled(FLB), following the method of Sherr et al. (1987). To remove any aggregated FLB, the FLB were dispersed throughout the medium using a sonicator (Bransoic cleaner 5510E-DTH; Bransoic, Danbury, CT, USA) for 10-30 min and then filtered through 3-μm pore-sized filter (Polycarbonate; Whatman, Dassel, Germany).

Plankton samples were collected with a water sampler from Shiwha Bay, Korea (37°18′ N, 126°36′ E), during September 2010, when the water temperature and salinity were 21.3°C and 15.6, respectively (Jeong et al. 2014a). The samples were filtered gently through a 154-μm Nitex mesh and placed in 6-well tissue culture plates. A clonal culture of *A. granifera* was established following two serial single-cell isolations. As the concentration of *A. granifera* increased, *A. granifera* was subsequently transferred to 32, 270, and 500 mL polycarbonate (PC) bottles containing fresh f/2 seawater media. The bottles were again filled to capacity with freshly filtered seawater, capped, and placed on a shelf at 20°C under 20 μE $m^{-2}s^{-1}$ illumination provided by cool white fluorescent lights in a 14 : 10 h light-dark cycle.

The carbon contents of *A. granifera* (0.11 ng C per cell) and *Pyramimonas* sp. (0.04 ng C per cell) were measured using a CHN Analyzer (vario MICRO; Elementar, Hanau, Germany) and those of the other phytoplankton species were obtained from our previous studies (Jeong et al. 2010a, 2011, 2012, Yoo et al. 2010, Kang et al. 2011).

Table 3-1. Taxa, sizes, and concentration of prey species offered as food to *Ansanella granifera* in Experiment 1.

Species	ESD (± SD)	Initial prey concentration (cells mL^{-1})	Feeding by *A. granifera*
Bacteria			
Heterotrophic bacteria	0.9 (0.3)	7,000,000	**Y**
Synechococcus sp.	1.0 (0.2)	7,000,000	**Y**
Diatoms			
Chaetoceros calcitrans	6.0 (0.2)	150,000	N
Skeletonema costatum	5.9 (1.1)	150,000	N
Prasinophytes			
Pyramimonas sp.	5.6 (0.1)	150,000	**Y**
Prymnesiophytes			
Isochrysis galbana	4.8 (0.2)	150,000	N
Cryptophytes			
Teleaulax sp.	5.6 (1.5)	100,000	N
Rhodomonas salina	8.8 (1.5)	50,000	N
Rhaphidophyte			
Heterosigma akashiwo	11.5 (1.9)	30,000	N
Dinoflagellates			
Heterocapsa rotundata (T)	5.8 (0.4)	100,000	N
Amphidinium carterae (NT)	9.7 (1.6)	30,000	N
Prorocentrum minimum (T)	12.1 (2.5)	15,000	N
Heterocapsa triquetra (T)	15.0 (4.3)	15,000	N
Scrippsiella trochoidea (T)	22.8 (2.7)	7,000	N

The abundances of the predator for each target prey were 5,000 cells mL^{-1}. ESD, mean equivalent spherical diameter (μm) ± standard deviation(SD) of the mean was measured by an electronic particle counter (Coulter Multisizer II; Coulter Corporation, Miami, FL, USA); Y, *A. granifera* was observed to feed on a living food cell; N, *A. granifera* was observed not to feed on a living food cell; T, thecate; NT, nonthecate. n>2,000 for each species.

Prey species

Experiment 1 was designed to investigate whether *A. granifera* was able to feed on different target algal species when unialgal diets of diverse algal species were provided (Table 3-1). The initial concentrations of each algal species offered were similar, in terms of carbon biomass. To confirm that some of the algal species were not ingested by *A. granifera*, additional higher prey concentrations were provided.

A dense culture (ca. 100,000-200,000 cells mL^{-1}) of *A. granifera* grown photosynthetically was transferred to a 1-L PC bottle containing f/2 medium and maintained in f/2 media for 2 d. Three 1-mL aliquots were then removed from the bottle and examined using a compound microscope to determine *A. granifera* concentration.

In this experiment, the initial concentrations of *A. granifera* and each target algal species were determined by using an autopipette to deliver a predetermined volume of culture with a known cell density to the experimental bottles. Triplicate 80-mL PC bottles with mixtures of *A. granifera* and the target prey and duplicate predator control bottles containing *A. granifera* only were set up for each target algal species. The bottles were filled to capacity with freshly filtered seawater, capped, and then placed on a vertically rotating plate at 0.9 rpm and incubated at 20°C under a 14 : 10 h light-dark cycle of cool white fluorescent light at 20 $\mu E\ m^{-2}s^{-1}$. After 12, 24, and 48h, a 5-mL aliquot was removed from each bottle and transferred into a 20-mL bottle. Two 0.1-mL aliquots were placed on slides and then covered with cover-glasses. Under these conditions, the *A. granifera* cells were alive, but almost stationary. The protoplasms of >100 *A. granifera* cells were carefully examined with a compound microscope and/or an epifluorescence microscope (Zeiss-Axiovert 200M; Carl Zeiss Ltd., Göttingen, Germany) at a magnification of ×100-630 to determine whether or not *A. granifera* was able to feed on target prey species. Images of the ingested cells of each target algal species inside *A. granifera* cells were taken using digital cameras mounted on the microscopes at a magnification of ×630-1,000.

For transmission electron microscopy (TEM), each of intact *Pyramimonas* cells *A. granifera* cell grown photosynthetically, and *A. granifera* cell satiated with *Pyramimonas* sp. was transferred to a 50-mL tube and fixed in 4% (v/v) glutaraldehyde in culture medium. After 1.5-2 h, the entire contents of the tube were placed in a 50-mL centrifuge tube and concentrated at 1,610 ×g for 10 min in a Vision Centrifuge (VS-5500; Vision Scientific Co., Bucheon, Korea). The pellet from the tube was then transferred to a 1.5-mL tube and rinsed with 0.2 M sodium cacodylic acid at pH 7.4. After several rinses in the medium, the cells were post-fixed in 1% (w/v) osmium tetroxide in deionized water. The pellet was then embedded in agar. Subsequently, the pellet was dehydrated using a graded ethanol series (i.e., 50, 60, 70, 80, 90 and 100% ethanol, followed by two 100% ethanol steps). The material was embedded in Spurr's low-viscosity resin (Spurr 1969). Sections were obtained using an RMC MT-XL ultramicrotome (Boeckeler Instruments Inc., Tucson, AZ, USA) and stained with 3% (w/v) aqueous uranyl acetate followed by 2% (w/v) lead citrate. The sections were observed using a JEOL-1010 electron microscope (JEOLLtd., Tokyo, Japan).

Feeding mechanisms

Experiment 2 was designed to investigate the feeding behaviors of *A. granifera* when a unialgal diet of *Pyramimonas* sp., the only algal prey, was provided. The ingestion of these prey species by *A. granifera* was observed in Experiment 1. The initial concentrations of predators and prey were the same as described previously.

The initial concentrations of *A. granifera* and the target algal species were established using an autopipette to deliver a predetermined volume of culture with a known cell density to the experimental bottles. One 80-mL PC bottle with a mixture of *A. granifera* and the algal prey was set up for each target algal species. The bottle was filled to capacity with freshly filtered seawater, capped, and then well mixed. After 1-min incubation, a 1-mL aliquot was removed from the bottle and transferred into a 1-mL Sedgewick-Rafter Chamber (SRCs). By monitoring the behavior of >30 unfed *A. granifera* cells for each target prey species under a compound microscope and/or an epifluorescence microscope at a magnification of ×100-630, all of the feeding processes were observed. A series of images showing the feeding process of a *A. granifera* cell was taken using a video analyzing system (Sony DXC-C33; Sony Co., Tokyo, Japan) mounted on an epifluorescence microscope at a magnification of ×100-630.

Growth and ingestion rates

Experiment 3 was designed to investigate the growth and ingestion rates of *A. granifera*. I measured the growth, ingestion, and clearance rates of *A. granifera* feeding on unialgal diet consisting of the optimal prey *Pyramimonas* sp. as a function of prey concentration.

A dense culture (ca. 32,000 cells mL^{-1}) of *A. granifera* growing photosynthetically was transferred into a 1-L PC bottle containing freshly filtered seawater. The culture was transferred into one 1-L PC bottle. Three 1-mL aliquots from the bottle were counted using a compound microscope to determine the cellular concentrations of *A. granifera* in each bottle, and the cultures were then used to conduct experiments.

The initial concentrations of *A. granifera* and *Pyramimonas* sp. were established as described previously. Triplicate 42-mL PC experimental bottles containing mixtures of predators and prey, triplicate prey control bottles containing prey only, and triplicate predator control bottles containing predators only were set up for each predator-prey combination. To ensure similar experimental conditions, the water from *A. granifera* culture was filtered through a 0.7-μm GF/F filter and added to the prey control bottles at similar amounts as the volume of the predator culture added to the experiment bottles for each predator-prey combination. Next, 5 mL of f/2 medium was added to all the bottles, which were then filled to capacity with freshly filtered seawater and capped. Five milliliters of f/2 medium were added to all bottles, which were then filled to capacity with freshly filtered seawater and capped. To determine the actual initial predator and prey densities (cells mL^{-1}) at the beginning of the experiment (*A. granifera* and *Pyramimonas* sp.: 16/237, 34/476, 51/2818, 49/5418, 96/11104, 291/71050, 525/133630) and after 2 d incubation, 5-mL aliquots were removed from each bottle and fixed with 5% Lugol's solution, and all *A. granifera* cells and all or >300 prey cells in three 1-mL SRCs were enumerated. Prior to taking the subsamples, the condition of *A. granifera* and its prey was assessed under a dissecting microscope. The bottles were filled again to capacity with f/2 medium, capped, placed on a vertically rotating plate rotating at 0.9 rpm, and incubated at 20°C under a 14 : 10h light-dark cycle with 20 μE $m^{-2}s^{-1}$ of cool white fluorescent light. The dilution of the cultures associated with refilling of the bottles was considered in calculating the growth and ingestion rates.

The specific growth rate of *A. granifera*, μ (d^{-1}), was calculated as follows:

$$\mu = \frac{\mathrm{Ln}\,(A_t/A_0)}{t} \qquad (1)$$

, where A_0 is the initial concentration of *A. granifera* and A_t is the final concentration after time t. The time period was 2d.

Data for *A. granifera* growth rate were fitted to the following equation:

$$\mu = \frac{\mu_{max}\ (x - x')}{K_{GR} + (x - x')} \qquad (2)$$

, where μ_{max} = the maximum growth rate (d^{-1}), x = prey concentration (cells mL^{-1} or ngC mL^{-1}), x' = threshold prey concentration (the prey concentration where μ = 0), and K_{GR} = the prey concentration sustaining 1/2 μ_{max}. Data were iteratively fitted to the model using DeltaGraph (SPSS Inc., Chicago, IL, USA).

Ingestion and clearance rates for 2 d were also calculated using the equations of Frost (1972) and Heinbokel (1978). The incubation times for calculating the ingestion and clearance rates were the same as for estimating the growth rate.

Ingestion rate data were fitted to a Michaelis-Menten equation:

$$IR = \frac{I_{max}\ (x)}{K_{IR} + (x)} \qquad (3)$$

, where I_{max}=the maximum ingestion rate (cells predator^{-1}d^{-1} or ng C predator^{-1} d^{-1}), x = prey concentration (cells mL^{-1} or ng C mL^{-1}), and K_{IR} = the prey concentration sustaining 1/2 I_{max}.

Cell volume of *Ansanella granifera*

After the 2-d incubation, the cell length and maximum width of *A. granifera* preserved in 5% acid Lugol's solution (n = 10-30 for each prey concentration) were measured using an image analysis system on images collected with a epifluorescence microscope (AxioVision 4.5; Carl Zeiss Ltd., Göttingen, Germany). The shape of *A. granifera* was estimated to be oval. The cell volume of the preserved *A. granifera* was calculated according to the following equation: volume = $4/3\ \pi\ [(\text{cell length} + \text{cell width}) / 4]^3$.

Swimming speed

A dense culture (ca. 50,000 cells mL^{-1}) of *A. granifera* growing photosynthetically was transferred into 500-mL PC bottle. An aliquot from the bottle was added to a 50-mL cell culture flask and allowed to acclimate for 30 min. The video camera was focused on one field seen as one circle in a cell culture flask under a dissecting microscope at 20°C and the movement of *A. granifera* cells was then recorded at a magnification of ×40 using a video analyzing system (SV-C660; Samsung, Seoul, Korea) and taken using a CCD camera (KP-D20BU; Hitachi, Tokyo, Japan). The mean and maximum swimming velocities were analyzed for all swimming cells seen for the first 10 min. The average swimming speed was calculated based on the linear displacement of cells in 1 s. during single-frame playback. The swimming speeds of 30 cells were measured.

Potential grazing impact

By combining field data on the abundances of the predators and the target prey with the ingestion rates of the predator on the prey obtained in the present study, I estimated the grazing coefficients attributable to *A. granifera* feeding on co-occurring *Pyramimonas* sp. Data on the abundances of *A. granifera* and the co-occurring *Pyramimonas* sp. used in this estimate were obtained by analyzing the water samples taken from the waters inside and outside Shiwha Bay, Korea in 2010～2013 using real-time PCR.

The grazing coefficients (g, d^{-1})were calculated as:

$$g = CR \times PC \times 24 \qquad (4)$$

, where CR (mL $predator^{-1}h^{-1}$)is the clearance rate of *A. granifera* feeding on a target prey at a prey concentration and PC is a predator concentration (cells mL^{-1}).The CR values were calculated as:

$$CR = IR / x \qquad (5)$$

, where IR (cells eaten $predator^{-1}h^{-1}$) is the ingestion rate of *A. granifera* feeding on the target prey and x (cells mL^{-1}) is the prey concentration. These CR values were corrected using Q_{10}=2.8(Hansen et al. 1997) because the insitu water temperature and the temperature used in the laboratory for this experiment (20°C) were sometimes different.

3-3. Results

Prey species

A. granifera was able to feed on heterotrophic bacteria and the cyanobacteria *Synechococcus* sp. (Fig. 3-1). In addition, among 12 algal prey species (5-23 μm in equivalent spherical diameter) offered, *A. granifera* ingested only *Pyramimonas* sp. (Table 3-1, Figs 3-1～3-3). TEM confirmed that *A. granifera* ingested *Pyramimonas* cells (Fig. 3-2). Intact *Pyramimonas* cells had the pyrenoids surrounded by starch. These pyrenoids with starch were conserved inside the food vacuoles of predator cells. However, it did not feed on the prymnesiophyte *Isochrysis galbana*, the diatoms (*Skeletonema costatum* and *Chaetoceros calcitrans*), cryptophytes (e.g., *Teleaulax* sp. and *Rhodomonas salina*), the raphidophyte *Heterosigma akashiwo*, the naked dinoflagellate (*Amphidinium carterae*), and thecate dinoflagellates (*Heterocapsa rotundata*, *Heterocapsa triquetra, Prorocentrum minimum*, and *Scrippsiella trochoidea*) (Table 3-1).

Feeding mechanisms

A. granifera fed on *Pyramimonas* sp. by engulfment after spinning a prey cell (Fig. 3-3). *A. granifera* did not try to attack the other algal species when encountering an algal cell. Furthermore, with the exception of *Pyramimonas* sp., it did not spin around a target cell.

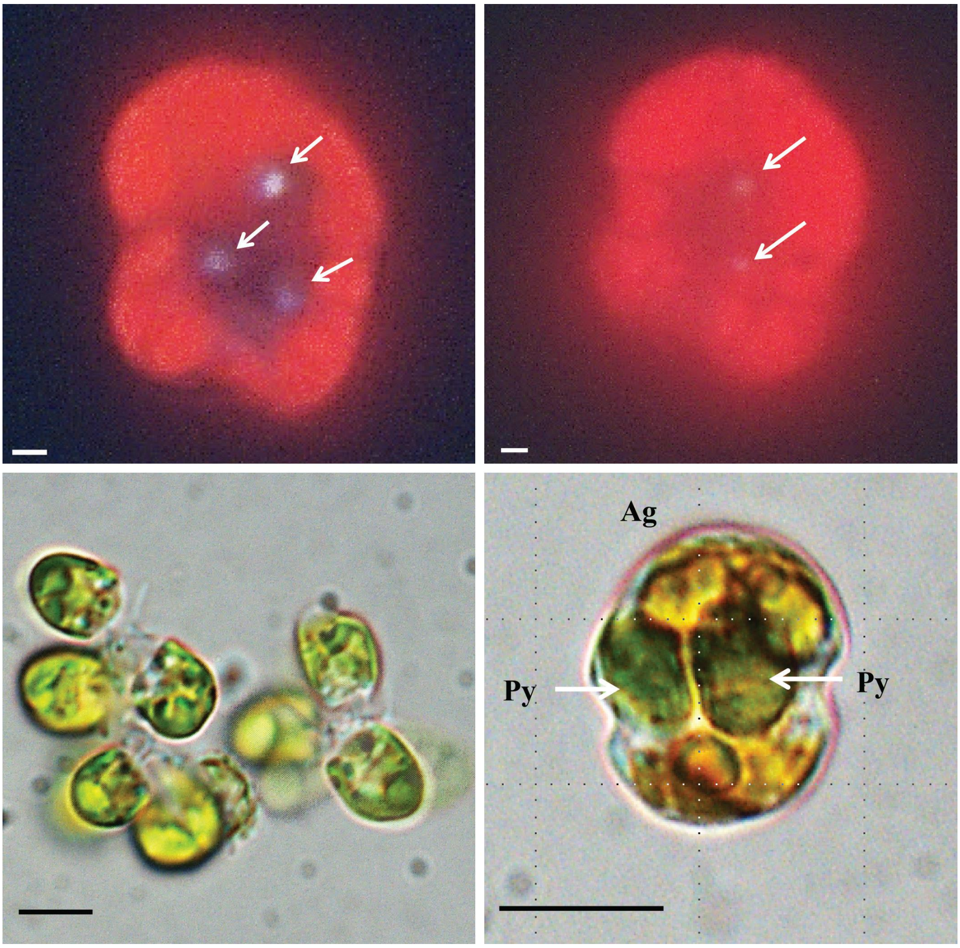


Fig. 3-1. Feeding by the mixotrophic dinoflagellate *Ansanella granifera* feeding on bacteria and the prasinophyte *Pyramimonas* sp. (A) An *A. granifera* cell with 3 ingested fluorescent-labeled bacteria (arrows). (B) An *A. granifera* cell with 2 ingested cyanobacterium *Synechococcus* sp. (arrows). (C) Unfed *Pyramimonas* cells. (D) An *A. granifera* (Ag) cell with 2 ingested *Pyramimonas* (Py) cells (arrows). Scale bars represent: A & B, 1 μm; C & D, 5 μm.

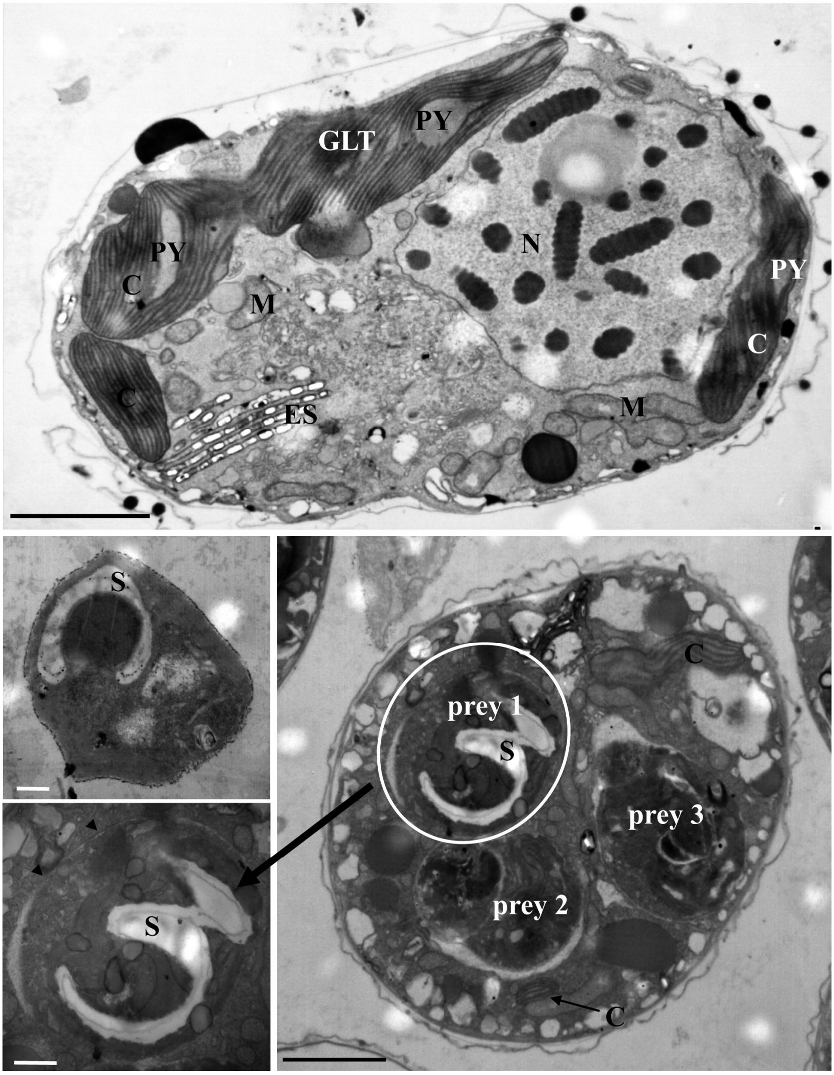


Fig. 3-2. Transmission electron micrographs (TEM) of *Ansanella granifera* and *Pyramimonas* sp. (A) A unfed *A. granifera* cell showing its chloroplasts (C), eyespot (ES), grana-like thylakoids (GLT), nucleus (N), mitochondria (M), and pyrenoid (PY). (B) Unfed *Pyramimonas* sp. cells showing starch (S). (C) An *A. granifera* cell with 3 ingested *Pyramimonas* sp. cells. (D) Enlarged image of Fig. 2C showing an ingested prey cell having starch (S) inside the food vacuole, arrowhead: food vacuole. Scale bars represent: A & C, 2 μm; B & D, 0.5 μm.

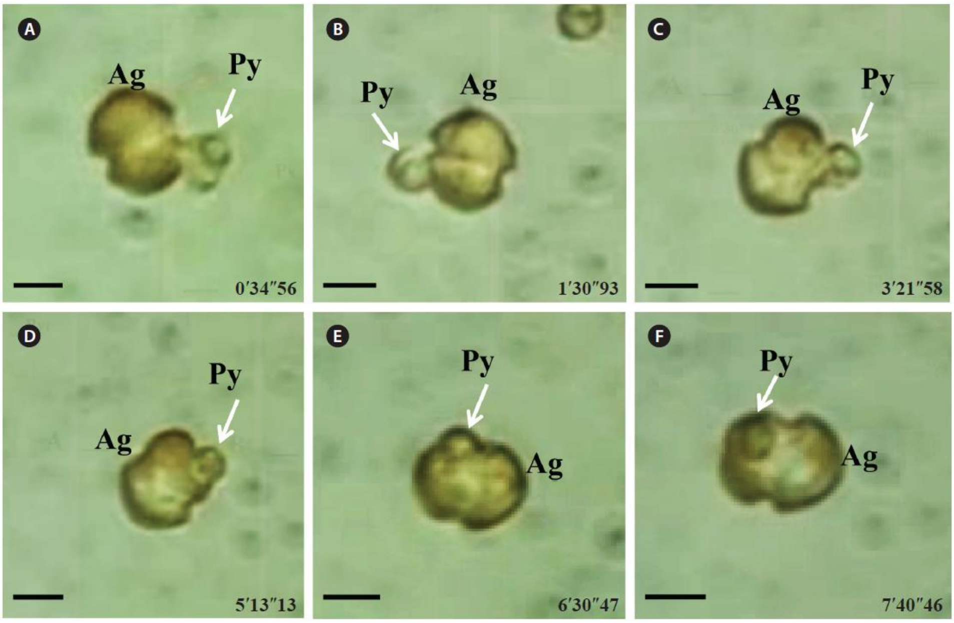


Fig. 3-3. (A-F) Feeding process of a *Ansanella granifera* cell (Ag) feeding on a *Pyramimonas* sp. cell (Py) by engulfment. The white arrow indicates the prey cell. Scale bars represent: A-F, 5 μm.

Growth and ingestion rates

With increasing mean prey concentration, the growth rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but became saturated at a concentration of 434 ng C mL^{-1} (10,845 cells mL^{-1})(Fig. 3-4). When the data were fitted to Eq.(2), the maximum specific growth rate (i.e., mixotrophic growth) of *A. granifera* feeding on *Pyramimonas* sp. was 1.426 d^{-1} at 20°C under a14:10h light-dark cycle of 20 μE $m^{-2}s^{-1}$, while its growth rate (i.e., phototrophic growth) under similar light conditions with out added prey was 0.391d^{-1}. The K_{GR} (i.e., the prey concentration sustaining 1/2 μ_{max}) was 148 ng C mL^{-1} (3,690 cells mL^{-1}).

With increasing mean prey concentration, the ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but slightly at concentrations ≥306 ng C mL^{-1} (7,649 cells mL^{-1}) (Fig. 3-5). When the data were fitted to Eq. (3), the maximum ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. was 0.973 ng C $predator^{-1}d^{-1}$ (24.3 cells $grazer^{-1}$ d^{-1}) and K_{IR} (the prey concentration sustaining 1/2 I_{max}) was 198 ng C mL^{-1} (4,958 cells mL^{-1}). The maximum clearance rate of *A. granifera* feeding on *Pyramimonas* sp. was 0.4 μL $grazer^{-1}$ h^{-1}.

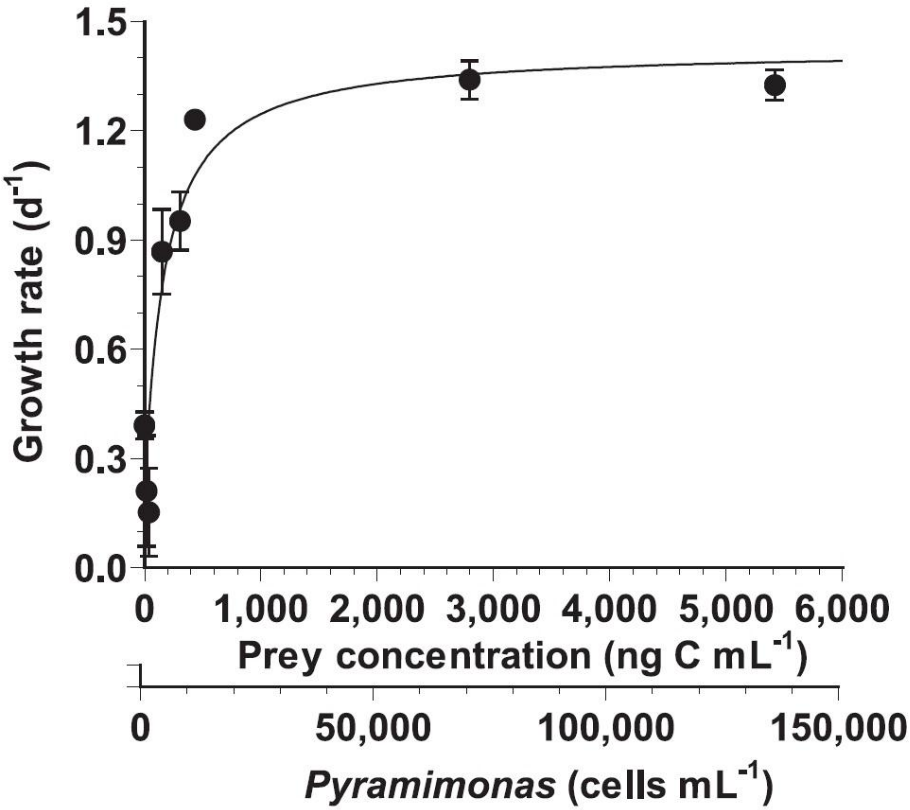


Fig. 3-4. Specific growth rate of *Ansanella granifera* feeding on *Pyramimonas* sp. as a function of mean prey concentration (x, ng C mL^{-1}). Symbols represent treatment means ± 1 standard error. The curve is fitted by a Michaelis-Menten equation [Eq. (2)] using all treatments in the experiment. Growth rate (GR, d^{-1})=1.426[(x + 22.03) / (147.6 + (x + 22.03)], r^2=0.854.

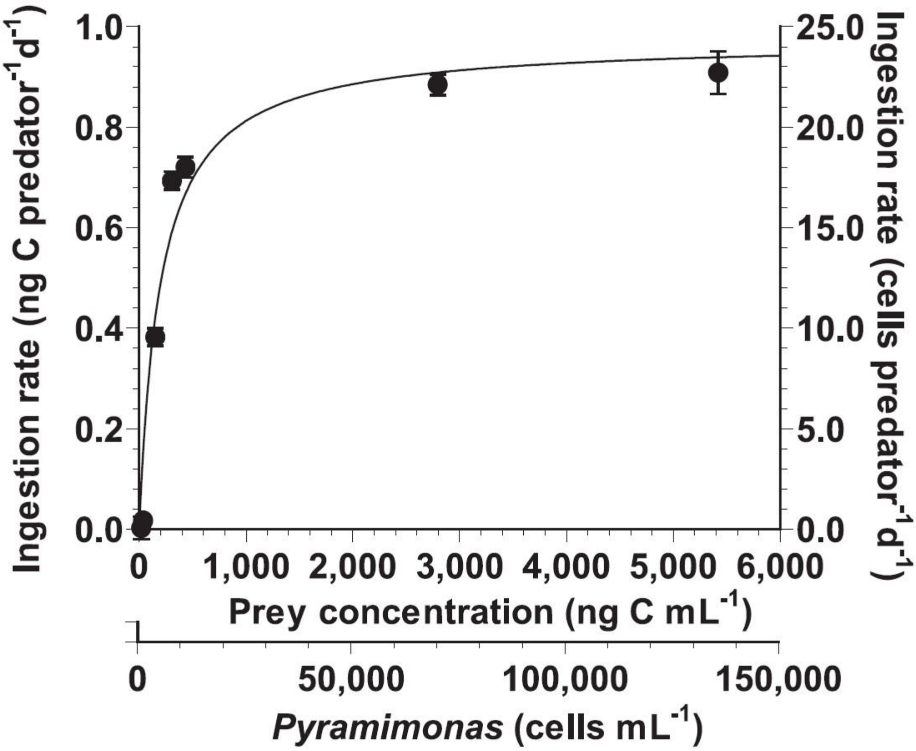


Fig. 3-5. Ingestion rate of *Ansanella granifera* feeding on *Pyramimonas* sp. as a function of mean prey concentration (x, ng C mL^{-1}).Symbolsrepresenttreatmentmeans±1standard error. The curve is fitted by a Michaelis-Menten equation [Eq. (3)] using all treatments in the experiment. (A) Ingestion rate (IR, d^{-1})=0.973[(x) / (198.3 + x))], r^2=0.948.

Cell volume

After a 2-d incubation, the mean cell volumes of *A. granifera* fed on *Pyramimonas* sp. at the lowest mean prey concentrations of 19-38 ng C mL^{-1} (446-471 μm^3) was comparable to those that were starved (492 μm^3) (Fig. 3-6). The cell volume increased rapidly up to 1,039 μm^3 at the mean prey concentration of 2,794 ng C mL^{-1} and then slowly up to 1,104 μm^3 at the mean prey concentration of 5,419 ng C mL^{-1}.

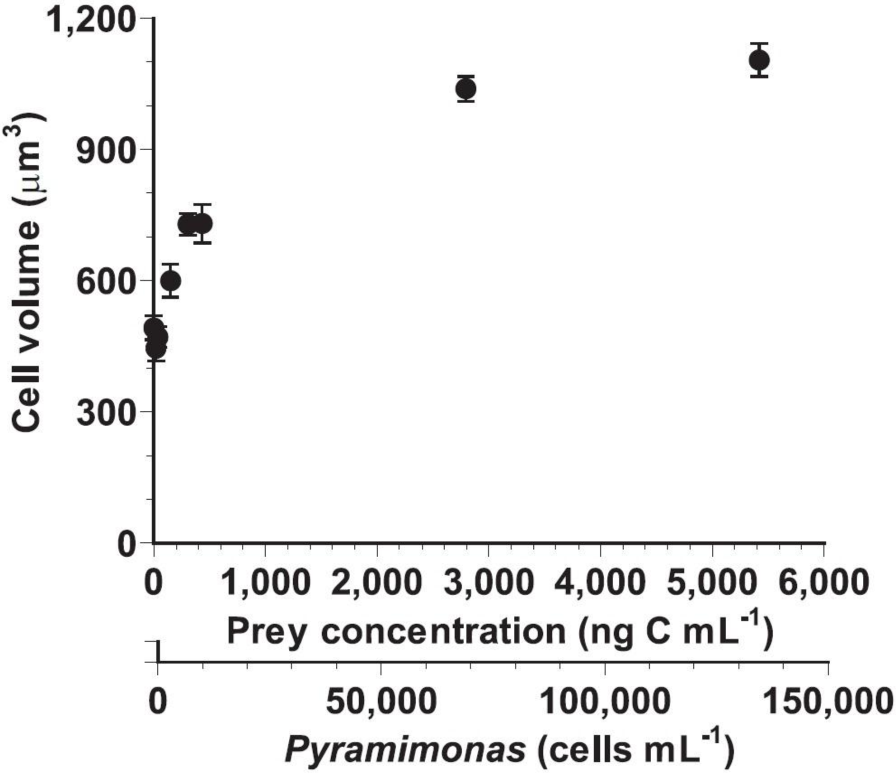


Fig. 3-6. The cell volume of *Ansanella granifera* feeding on *Pyramimonas* sp. after a 48-h incubation as a function of mean prey concentration. Symbols represent treatment means ± 1 standard error.

Swimming speed

A. granifera swam with alternating slow moving and very quick moving swims. The average (± standard error, n = 30) and maximum swimming speeds of *A. granifera* in the given conditions were 802 (± 51) and 1,603 $\mu m\ s^{-1}$, respectively.

Potential grazing impact

The grazing coefficients attributable to *A. granifera* feeding on co-occurring *Pyramimonas* sp. in the water samples taken in the waters of Shiwha Bay, Korea in 2010-2013 (n = 20), when the concentrations of *Pyramimonas* sp. and *A. granifera* were 3-53,243 cells mL^{-1} and 1-403 cells mL^{-1}, respectively, were 0.003-2.78d^{-1} (Fig. 3-7). The highest grazing coefficient was obtained when the concentration of *Pyramimonas* sp. and *A. granifera* were 1,053 cells mL^{-1} and 403 cells mL^{-1}, respectively. In 11 of 20 samples, the grazing coefficients attributable to *A. granifera* feeding on co-occurring *Pyramimonas* sp. exceeded 0.02 d^{-1}.

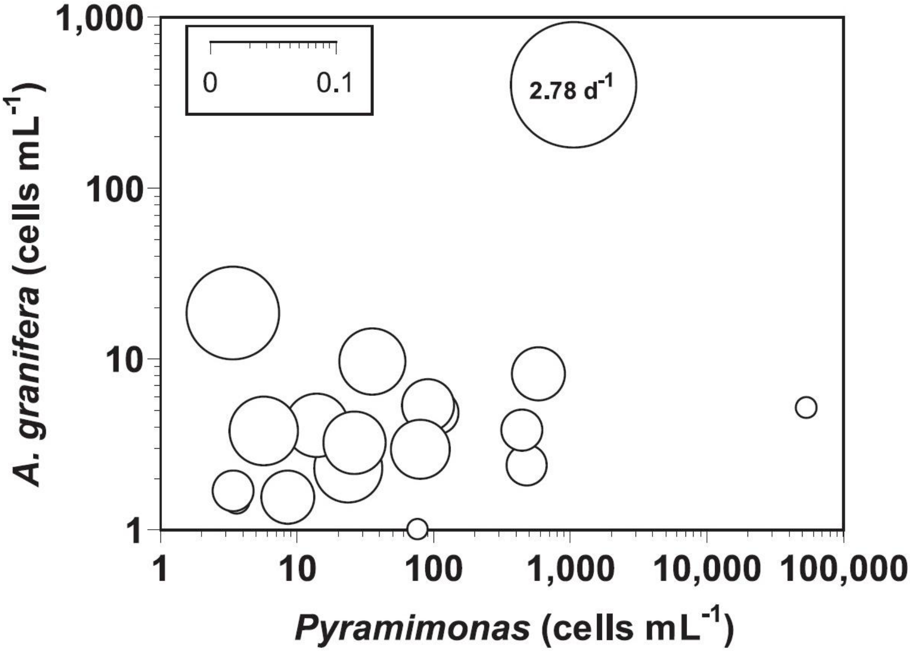


Fig. 3-7. Calculated grazing coefficients (g, h^{-1}) attributable to *Ansanella granifera* feeding on natural populations of *Pyramimonas* sp. (see text for calculation) (n = 12).

3-4. Discussion

Feeding mechanisms and prey species

The mixotrophic dinoflagellate *A. granifera* fed on algal prey by engulfment. Similar-sized and shaped mixotrophic dinoflagellates *Biecheleria cincta* (previously *Woloszynskia cincta*), *Gymnodinium aureolum*, *Karlodinium armiger*, and *Paragymnodinium shiwhaense*, along with the heterotrophic dinoflagellates *Gyrodiniellum shiwhaense*, *Luciella masanensis*, *Pfiesteria piscicida*, and *Stoeckeria algicida*, feed on algal prey using a peduncle (Burkholder et al. 1992, Jeong et al. 2005a, 2006, 2007, 2010a, 2011, Berge et al. 2008a, Yoo et al. 2010, Kang et al. 2011). However, the peduncle is not found inside the protoplasm of *A. granifera* cells. Among the algal prey tested, *A. granifera* was only able to feed on the prasinophyte *Pyramimonas* sp. (5.6 μm in ESD). In general, engulfment-feeding dinoflagellates are able to ingest prey cells that are smaller than themselves, whereas peduncle-feeding dinoflagellates are able to feed on prey cells that are larger than themselves (Jeong et al. 2005a, 2005d, 2010a, Lim et al. 2014). The small size and engulfment feeding mechanism of *A. granifera* may be responsible for its feeding on only small *Pyramimonas* sp. The heterotrophic dinoflagellate *S. algicida* is able to feed only on the raphidophyte *H. akashiwo*, while the sister species, *Stoeckeria changwonensis* is able to feed on diverse prey species (Jeong et al. 2005a, Lim et al. 2014). However, the maximum growth and ingestion rates of *S. algicida* are greater than those of *S. changwonensis*. Therefore, Lim et al.(2014) suggested that diversification of prey items and feeding intensity may be traded during evolution. The maximum growth and ingestion rates of *A. granifera* on *Pyramimonas* sp. are comparable to or greater than those of other dinoflagellate predators (see next section). It will be worthwhile exploring the relationship between the number of prey species and feeding activity of other mixotrophic and heterotrophic dinoflagellates. One or few prey species may limit the period in which these predators appear and cause large fluctuations in their abundance.

Pyramimonas spp. sometimes causes red tides or harmful algal blooms (Bird and Karl 1991, Gradinger 1996, Alonso-Rodŕiguez et al. 2000, Daugbjerg et al. 2000, Rodriguez et al. 2002, Kang et al. 2013). Prior to this study, *K. armiger* was the only mixotrophic dinoflagellate known to feed on *Pyramimonas* sp. (Berge et al. 2008a, 2008b). *A. granifera* is now one of the two mixotrophic dinoflagellates that have been reported to feed on *Pyramimonas* spp. (Table 3-2). The heterotrophic dinoflagellates *Gyrodinium dominans*, *Gyrodinium spirale*, and *Oblea rotunda*, and the ciliates *Laboea strobili* and *Strombidinopsis* sp. are known to feed on *Pyramimonas* spp. (Jacobson and Anderson 1986, Stoecker et al. 1988, Putt 1991, Hansen 1992, Nakamura et al. 1995). However, to date, positive growth rates of only *G. dominans, K. armiger*, and *A. granifera* have been reported. Therefore, during *Pyramimonas* blooms, *G. dominans, K. armiger*, and *A. granifera* may be abundant. To predict the population dynamics of *G. spirale, O. rotunda, L. strobili*, and *Strombidinopsis* spp. during *Pyramimonas* blooms, it will be worthwhile measuring the growth and ingestion rates of these predators on *Pyramimonas* spp.

Table 3-2. Protistan grazers on *Pyramimonas* spp.

Predator	Prey	ESD	GR	IR	Reference
Mixotrophic dinoflagellates					
Ansanella granifera	*Pyramimonas* sp.	5.6	1.43	0.97	This study
Karlodinium armiger	*P. orientalis*	5.6	0.45	0.02	Berge et al. (2008*a*, 2008*b*)
Karlodinium armiger	*P. propulsa*	10.7	NA	NA	Berge et al. (2008*a*, 2008*b*)
Heterotrophic dinoflagellates					
Oblea rotunda	*Pyramimonas* sp.	NA	NA	NA	Jacobson and Anderson (1986)
Gyrodinium dominans	*P. parkeaea*	10.5	0.03-0.1	NA	Nakamura et al. (1995)
Gyrodinium spirale	*Pyramimonas* sp.	6.6	NA	NA	Hansen (1992)
Ciliates					
Laboea strobila	*Pyramimonas* sp.	NA	NA	NA	Stoecker et al. (1988)
Strombidinopsis sp.	*Pyramimonas* sp.	NA	NA	NA	Putt (1991)

ESD, mean equivalent spherical diameter (μm); GR, growth rate (d^{-1}); IR, ingestion rate (ng C $predator^{-1}d^{-1}$); NA, not available.

Growth and ingestion rates

The maximum growth rate of *A. granifera* feeding on *Pyramimonas* sp. (1.426 d^{-1}) is much greater than that of *K. armiger* feeding on *Pyramimonas orientalis* (0.45 d^{-1}) (Table 3-2). The maximum ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. (0.973 ng C $predator^{-1}d^{-1}$) is much greater than that of *K. armiger* on *P. orientalis* (0.02 ng C $predator^{-1}d^{-1}$). The cell size of *A. granifera* (10.5 μm in ESD) is smaller than that of *K. armiger* (16.7 μm). Therefore, the much higher ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. and smaller cell size may be partially responsible for this greater growth rate.

The ratio of the mixotrophic growth rate (1.426 d^{-1}) relative to the autotrophic growth rate (0.391d^{-1}) of *A. granifera* feeding on *Pyramimonas* sp. at 20°C under a 14:10h light-dark cycle of 20 μE $m^{-2}s^{-1}$, 3.7, is greater than that of any other mixotrophic dinoflagellates except *K. armiger* on *Rhodomonas baltica, Dinophysis acuminata* on *Mesodinium rubrum*, and *B. cincta* (previously *W. cincta*) on *H. akashiwo* (Table 3-3). Furthermore, the difference between autotrophic and mixotrophic growth rates of *A. granifera* feeding on *Pyramimonas* sp., which is 1.04, is greater than any other mixotrophic dinoflagellate except *P. shiwhaense* on *A. carterae* (Table 3-3). Therefore, *A. granifera* can acquire growth materials and energy through feeding much more than photosynthesis compared to other mixotrophic dinoflagellates, except a few species. Mixotrophy in *A. granifera* may be a critical strategy in increasing its population.

The maximum growth rate of *A. granifera* feeding on the optimal prey obtained under a 14 : 10 h light-dark cycle of 20 μE $m^{-2}s^{-1}$ (1.426 d^{-1}) is lower than that of *Gymnodinium smaydae* (2.23 d^{-1}) (Lee et al. 2014), but higher than that of any other mixotrophic dinoflagellate so far reported (0.20-1.10 d^{-1}) at diverse light intensities (Table 3-3). Even though *G. smaydae* has the highest mixotrophic growth rate among dinoflagellates, it cannot grow well photosynthetically. High mixotrophic and autotrophic growth rates enable *A. granifera* to slowly increase its population when the concentration of *Pyramimonas* spp. is low, but rapidly increase when that of *Pyramimonas* spp. is high.

The maximum ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. (0.97 ng C $predator^{-1}d^{-1}$) is also greater than that of the mixotrophic dinoflagellates *Karlodinium veneficum, Gyrodinium galathenum, P. shiwhaense, Prorocentrum donghainese*, which are similar in size to *A. granifera* (0.03-0.38 ng C $predator^{-1}d^{-1}$) (Table 3-3). *A. granifera* feeds on only *Pyramimonas* sp., while the other mixotrophic dinoflagellates can feed on diverse algal prey species (Li et al. 1999, Jeong et al. 2005d, Adolf et al. 2006). Therefore, *A. granifera* may have adapted to feed on *Pyramimonas* sp. unlike other mixotrophic dinoflagellates.

When the data on maximum mixotrophic and ingestion rates of *A. granifera* and other mixotrophic dinoflagellates so far reported were analyzed, the maximum ingestion rates of all mixotrophic dinoflagellates feeding on the optimal prey species were significantly correlated with the size of the predator ($p < 0.01$, a linear regression ANOVA) (Fig. 3-8). Furthermore, the maximum ingestion rates of engulfment feeders are also significantly correlated with the size of the predator ($p < 0.01$, a linear regression ANOVA), but those of the peduncle feeders were not significantly correlated ($p > 0.1$). This suggests that large engulfment feeding mixotrophic dinoflagellates may ingest more prey cells than smaller ones, but peduncle feeding mixotrophic dinoflagellates may not. The maximum mixotrophic growth rates of all mixotrophic dinoflagellates feeding on the optimal prey species were not significantly correlated with the size of the predator ($p > 0.1$, a linear regression ANOVA). Difference in nutritional values of the optimal prey species for each predator and/or growth efficiency may have contributed to the absence of a significant correlation.

Table 3-3. Optimal prey and maximum mixotrophic growth (MMGR), ingestion (MIR), and clearance rates of each mixotrophic dinoflagellate predator species

Predator	ESD	Optimal prey	ESD	RPP	T	LI	MMGR	AGR	RMAG	(M-A)	MIR	Reference
Engulfment feeding												
Ansanella granifera	10.5	*Pyramimonas* sp.	5.6	1.9	20	20	1.43	0.39	3.7	1.04	0.97	This study
Gyrodinium galatheanum	11.0	*Storeatula major*	6.6	2.0	20	372-384	0.94	0.32	2.9	0.62	0.12	Li et al. (1999)
Prorocentrum donghaiense	13.2	*Teleaulax* sp.	5.6	2.4	20	20	0.51	0.38	1.4	0.14	0.03	Jeong et al. (2005*c*)
Heterocapsa triquetra	15.0	*Teleaulax* sp.	5.6	2.7	20	20	0.28	0.18	1.5	0.10	0.04	Jeong et al. (2005*c*)
Karlodinium armiger[a]	16.7	*Rhodomonas baltica*	10.7	1.6	15	180	0.65	0.06	10.8	0.59	0.97	Berge et al. (2008*b*)
Cochlodinium polykrikoides	25.8	*Teleaulax* sp.	5.6	4.6	20	50	0.32	0.17	2.0	0.16	0.16	Jeong et al. (2004)
Prorocentrum micans	26.6	*Teleaulax* sp.	5.6	4.8	20	20	0.20	0.11	1.9	0.09	0.04	Jeong et al. (2005*c*)
Amylax triacantha	30.0	*Mesodinium rubrum*	22.0	1.4	15	20	0.68	-0.08	-8.5	0.76	2.54	Park et al. (2013*b*)
Gonyaulax polygramma	32.5	*Teleaulax* sp.	5.6	5.8	20	50	0.28	0.19	1.5	0.09	0.18	Jeong et al. (2005*d*)
Lingulodinium polyedrum	36.6	*Scrippsiella trochoidea*	25.1	1.5	20	50	0.30	0.18	1.7	0.12	0.36	Jeong et al. (2005*c*)
Fragilidium subglobosum	45.0	*Ceratium tripos*	59.5	0.8	15	45	0.50	0.16	3.1	0.34	6.27	Hansen and Nielsen (1997)
Fragilidium cf. *mexicanum*	54.5	*Lingulodinium polyedrum*	37.9	1.4	22	20	0.36	-0.05	-7.2	0.41	7.00	Jeong et al. (1999)
Peduncle feeding												
Gymnodinium smaydae	10.5	*Heterocapsa rotundata*	9.5	1.1	20	20	2.23	0.01	>10	1.60	1.60	Lee et al. (2014)
Karlodinium veneficum	11.0	*Storeatula major*	6.6	2.0	20	250	0.75	0.55	1.4	0.20	0.13	Adolf et al. (2006)
Symbiodinium voratum	11.1	*Heterosigma akashiwo*	11.5	1.0	20	20	0.47	0.30	1.6	0.17	0.53	Jeong et al. (2012)
Paragymnodinium shiwhaense	12.4	*Amphidinium carterae*	9.7	1.3	20	20	1.10	-0.22	-4.9	1.32	0.38	Yoo et al. (2010)
Biecheleria cincta	13.4	*Heterocsigma akashiwo*	11.5	1.2	20	20	0.50	0.04	12.5	0.46	0.49	Kang et al. (2011)
Gymnodinium aureolum	19.4	*Teleaulax* sp.	5.6	3.5	20	20	0.17	0.12	1.4	0.05	0.06	Jeong et al. (2010*a*)
Dinophysis acuminata	35.0	*Mesodinium rubrum*	22.0	1.6	20	60	0.95	0.19	5.0	0.76	1.30	Kim et al. (2008)

ESD, equivalent spherical diameter (m); RPP, ratio of predator to prey ESD; T, temperature (°C); LI, light intensity ($\mu E\ m^{-2}s^{-1}$); MMGR, maximum mixotrophic growth rate (d^{-1}); AGR, autotrophic growth rate (d^{-1}); RMAG, ratio of mixotrophic to autotrophic growth rates; (M-A), (MMGR-AGR); MIR, maximum ingestion rate (ng C $predator^{-1}d^{-1}$).

[a]Indicates the capability of feeding both peduncle and engulfment. Berge et al. (2008a) suggested that *Karlodinium armiger* fed on *Rhodomonas baltica* mainly by engulfment.

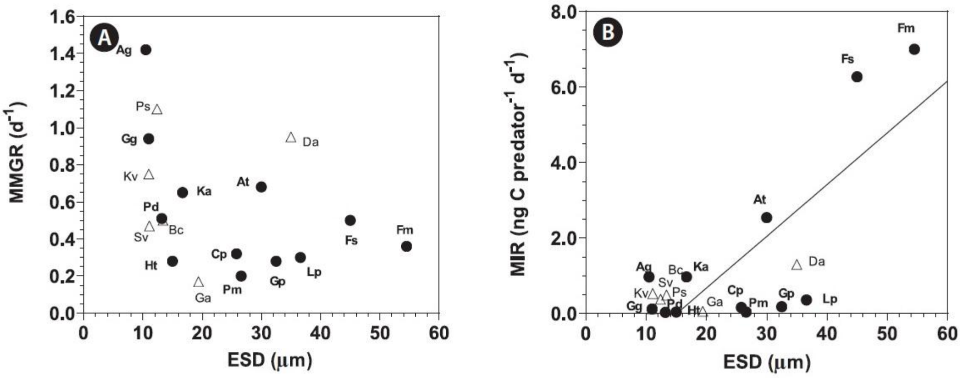


Fig. 3-8. The maximum mixotrophic growth (MMGR) (A) and ingestion rates (MIR) (B) of mixotrophic dinoflagellates feeding on optimal prey species by engulfment (close circles) and peduncle (open triangles) as a function of the size (equivalent spherical diameters [ESD, μm]) of the predator (see Table 3-3). The equation of the regression was MIR (ng C predator^{-1}d^{-1}) = 0.1197 × (ESD of predator) - 1.592, r^2=0.579 for all mixotrophs (n = 18, p < 0.01); MIR (ng C predator^{-1}d^{-1}) = 0.1371 × (ESD of predator) - 2.07, r^2=0.604 for engulfment feeders (n = 16, p < 0.01). MIR of the peduncle feeders and MMGR were not significantly correlated with ESD of predators (p > 0.1). Ag, *Ansanella granifera*; At, *Amylax triacantha*; Bc, *Biecheleria cincta*; Cp, *Cochlodinium polykrikoides*; Da, *Dinophysis acuminata*; Fm, *Fragilidium* cf. *mexicanum*; Fs, *Fragilidium subglobosum*; Ga, *Gymnodinium aureolum*; Gg, *Gyrodinium galatheanum*; Gp, *Gonyaulax polygramma*; Ht, *Heterocapsa triquetra*; Ka, *Karlodinium armiger*; Kv, *Karlodinium veneficum*; Lp, *Lingulodinium polyedrum*; Pd, *Prorocentrum donghaiense*; Pm, *Prorocentrum micans*; Ps, *Paragymnodinium shiwhaense*; Sv, *Symbiodinium voratum.*

Swimming speed

The average and maximum swimming speeds of *A. granifera* in the given conditions, 802 and 1,603 μm s^{-1}, respectively, are greater than those of any other mixotrophic dinoflagellate. These values are greater than those of the dinoflagellate *Cochlodinium polykrikoides*, the fastest mixotrophic dinoflagellate previously reported (1,063 and 1,449 μm s^{-1}, respectively). Thus, *A. granifera* appears to be the fastest mixotrophic dinoflagellate reported to date. Mixotrophic dinoflagellates can increase their populations by migrating between wet-lit surface water and eutrophicated bottom water (Eppley and Harrison 1975, Park et al. 2001). Thus, the ability of fast swimming may enable *A. granifera* to reach depths deeper than those reached by other mixotrophic dinoflagellate in vertical migration. When the thermocline is located deep, *A. granifera* may have an advantage over other competitors in meeting eutrophicated bottom water.

Grazing impact

The grazing coefficients attributable to *A. granifera* feeding on co-occurring *Pyramimonas* sp. obtained in the present study were up to 2.78 d^{-1} (i.e., 93% of the population of *Pyramimonas* sp. was removed by *A. granifera* populations in 1 d). In 11 of 20 samples, the grazing coefficients attributable to *A. granifera* feeding on co-occurring *Pyramimonas* sp. exceeded 0.02 d^{-1} (i.e., $\geq$2% of the population of *Pyramimonas* sp. was removed by *A. granifera* populations in 1 d). Therefore, *A. granifera* has the potential to sometimes have a considerable grazing impact on populations of co-occurring *Pyramimonas* sp.

3-5. Conclusion

To investigate the feeding of newly described mixotrophic dinoflagellate *A. granifera*, I explored the feeding mechanism and the different types of species that *A. granifera* was able to feed on. In addition, I measured the growth and ingestion rates of *A. granifera* feeding on the prasinophyte *Pyramimonas* sp., the only algal prey, as a function of prey concentration.

1. *A. granifera* was able to feed on heterotrophic bacteria and the cyanobacterium *Synechococcus* sp. However, among the 12 species of algal prey offered, *A. granifera* ingested only *Pyramimonas* sp. *A. granifera* ingested the algal prey cell by engulfment.

2. With increasing mean prey concentration, the growth rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but became saturated at a concentration of 434 ng C mL^{-1} (10,845 cells mL^{-1}). The maximum specific growth rate (i.e., mixotrophic growth) of *A. granifera* feeding on *Pyramimonas* sp. was 1.426 d^{-1}, at 20°C under a 14 : 10 h light-dark cycle of 20 μE m^{-2} s^{-1}, while the growth rate (i.e., phototrophic growth) under similar light conditions without added prey was 0.391 d^{-1}.

3. With increasing mean prey concentration, the ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but slightly at the concentrations ≥306 ng C mL^{-1} (7,649 cells mL^{-1}). The maximum ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. was 0.97 ng C $predator^{-1}$ d^{-1} (24.3 cells $grazer^{-1}$ d^{-1}). The calculated grazing coefficients for *A. granifera* feeding on co-occurring *Pyramimonas* sp. were up to 2.78 d^{-1}.

4. The results of the present study suggest that *A. granifera* can sometimes have a considerable grazing impact on the population of *Pyramimonas* spp.

4. Overall conclusion

The marine organisms are known to be sensitive to temperature changes. Due to global warming, the oceanic temperature is increasing, and moreover, the water temperature near the nuclear power plant can increase more rapidly because of thermal condenser effluent. Each phytoplankton species has optimal and tolerable water temperature range. Thus, elevation of the water temperature may change the phytoplankton communities. Therefore, influences of temperature increase in oceanic phytoplankton communities near nuclear power plants need to be analysed.

Nuclear power plants, which require large amounts of cooling water, are continuous source of heat to near by ocean. Each unit discharges about 50 $m^3 \cdot sec^{-1}$ of cooling water which increases water temperature 7~9℃. The operating nuclear power plant affects marine ecosystem in several ways. By drawing large quantities of seawater used for cooling in condenser systems, it exposes planktonic organisms to acute thermal, mechanical, and chemical stresses. The most significant effect on marine environment by the nuclear power plants is deemed to be from the thermal discharge effluent.

To predict the effect of global warming and temperature rise of seawater on marine ecosystems, (1) physicochemical properties of seawater near nuclear power plants were determined, and abundance and biomass of phytoplankton were analyzed. Furthermore, (2) seasonal data were analyzed with respect to temperature rise. (3) Based on the seawater properties and phytoplankton communities, effects of the temperature rise on marine ecosystems were predicted.

In this study, the relationship between phytoplankton community and increase in water temperature is analyzed based on data collected near nuclear power plants over 11 year period from 1999 to 2009. In this presentation, the study is focused on phytoplankton communities in waters around Hanbit nuclear power plant in Yonggwang located on West Sea coast and Hanul nuclear power plants in Ulchin located on East Sea coast. The total flow rates are 337.2 m^3 sec^{-1} in Hanbit and 318.2 m^3 sec^{-1}in Hanul.

On a positive viewpoint, the thermal discharged can be considered as thermal enrichment. On a neutral viewpoint, this can be considered as thermal dispersion. On a negative viewpoint, this can be considered as thermal pollution.

The micro-organisms entrained in condenser are affected by thermal effects from temperature rise, chemical effect from chlorides, and mechanical effect from collision with intake.

The West Sea has larger tidal range than East Sea. The average current velocity around Hanbit nuclear power plant site ranges from 10~30 cm sec^{-1} and maximum velocity ranges from 40~70 cm sec^{-1}. In Hanul nuclear power plant site, average current velocity ranges from 5~15 cm sec^{-1} and maximum velocity ranges from 15~20 cm sec^{-1}. Between 1999 to 2009, temperature varied from 2.4 to 37.6℃ in Hanbit site and from 7.8 to 30.2℃ in Hanul site. Since the water temperature at Hanbit site show wider variation than Hanul site, the temperature range of Hanbit site 2~38℃ were used and data were analyzed in 3℃ intervals. The Hanbit and Hanul site showed different characteristics such as nutrient contents, transparency and tidal current. But they also showed some similarity, such as diatoms and dinoflagellate being the dominant species in terms of biological aspect, and showing 2 biomass peaks per year.

In both sites, the phytoplankton growth seemed to be limited by contents of dissolved inorganic phosphate. In both sites, the changes in total phytoplankton coincided with changes of diatom, which was the dominant species. Biomass peaks for diatom were observed at 11℃ and 32℃ for Hanbit and 14℃ and 20℃ for Hanul. However, peaks for dinoflagellate were observed at higher temperatures than diatom with peaks at 14℃, 29℃ and 35℃ for Hanbit. For Hanul, the biomass of dinoflagellate increased from 14℃ to 20℃ and decreased above 20℃.

The total concentration of chlorophyll *a* in Hanbit area had range of 0.48 ~ 27.10 ug L^{-1}, and that in Hanul area had range of 0.02 ~ 5.27 ug L^{-1} which was less than Hanbit area. When phytoplankton was divided into net phytoplankton(larger than 20 microns) and nano phytoplankton(less than 20 microns) and chlorophyll *a* was compared with water temperature, data from Hanbit showed net peak values at 11℃ and 26～29℃ and similar trend was found in data from Hanul. At temperatures where the phytoplankton abundance was high, the chlorophyll *a* of net plankton was dominant. At low temperatures and very high temperature (above 35℃ in Hanbit), chlorophyll *a* of nano plankton was dominant.

The relationship between temperature and physical, chemical and biological factors were analyzed. Additional data from the National Ocean Environmental Measurement System(NOEMS) were obtained and analyzed to find changes in the environment that was not related to existence nuclear power plant. The comparison of physicochemical items between NOEMS data and data from the Hanbit and Hanul NPP area from this study showed that except for temperature elevation at the discharge, there were no noticeable differences in environment.

The effect of temperature elevation was not always negative. In the winter, warm discharge water from Hanbit had positive effect of increasing abundance at the discharge station.

When productivities were compared in terms of temperature elevation, nutrients and chlorophyll *a* contents, temperature elevation and other parameters such as nutrients had combined effect on phytoplankton communities, rather than temperature elevation alone. From observed changes in chlorophyll *a* concentrations, phytoplankton growth inhibition from thermal shocks were not distinguishable from mechanical shocks at discharge temperatures below 30℃.

In summary, effect of nuclear power plant discharge on the near by marine ecosystem were studied. While the power plant was discharging water at temperatures higher than the surround area, this did not directly correlate to productivity of phytoplankton. The community structure of phytoplankton also depended on other factors such as nutrient concentrations.

The effect of warm water discharge from nuclear power plant were studied by observing changes in biomass with temperature, with additional consideration of other parameters such as physical, chemical and biological components. Appearance of certain species with changes in water temperature were also studied. From these studies, temperature increase due to global warming will result in increased fraction of dinoflagellates in the total phytoplankton communities. Also, higher increase of eurythermal and high-temperature adapted plankton rather than low temperature adapted plankton is expected. In addition, increase in water temperature will make other parameters such as concentration of nutrients likely become more important.

Through this study, (1) quantitative evaluation of the effect of thermal discharge effluent on marine ecology, especially on abundance and biomass of phytoplankton were performed and found that during low temperature period, the thermal discharge sustained or increase phytoplankton abundance. Also, similar amount of thermal discharge had different effect on West coast and East coast. (2) Phytoplankton growth for each species as functions of temperature were obtained from field analysis and through similar experiments and literature survey, and it was found that phytoplankton species are likely to thrive with rise in water temperature. (3) The result of this study is applicable in predicting changes in marine phytoplankton community as a result of global warming.

Phototrophic dinoflagellates are one of the major components in marine planktonic communities. For a long time, these dinoflagellates were treated as phytoplankton, which can survive only by photosynthesis. However, in the last 2 decades, tens of phototrophic dinoflagellates have been revealed to be mixotrophic; they are known to feed on diverse prey, such as heterotrophic bacteria, cyanobacteria, small flagellates, other mixotrophic dinoflagellates, and ciliates. Thus, discovery of mixotrophy in phototrophic dinoflagellates increase the complexity in food webs, but help in better understanding predator-prey relationships and cycling of materials in the food webs. Some mixotrophic dinoflagellates sometimes have considerable grazing impact on populations of prey species. Recently, several new genera and/or species of phototrophic dinoflagellates have been established.

Recently, I found a new mixotrophic dinoflagellate *Ansanella granifera* in Shiwha Bay, Korea. I established a clonal culture of *A. granifera* and observed its feeding behavior under high-resolution video-microscopy in order to explore the feeding mechanisms and determine the prey species when diverse algal species were provided. I also conducted experiments to determine the effects of prey concentration on the growth and ingestion rates of *A. granifera* feeding on the prasinophyte *Pyramimonas* sp., the only algal prey, as a function of prey concentration. In addition, I estimated the grazing coefficients attributable to *A. granifera* feeding on *Pyramimonas* sp. using the ingestion rate obtained from the laboratory experiments and the abundances of predators and prey in the field. The abundances of *A. granifera* and *Pyramimonas* sp. were quantified using real-time polymerase chain reaction (PCR). The results of the present study provide a basis for understanding the feeding mechanisms and ecological roles of *A. granifera* in marine planktonic food webs.

With increasing mean prey concentration, the growth rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but became saturated at a concentration of 434 ng C mL^{-1} (10,845 cells mL^{-1}). The maximum specific growth rate (i.e., mixotrophic growth) of *A. granifera* feeding on *Pyramimonas* sp. was 1.426 d^{-1}, at 20°C under a 14 : 10 h light-dark cycle of 20 µE m^{-2} s^{-1}, while the growth rate (i.e., phototrophic growth) under similar light conditions without added prey was 0.391 d^{-1}. With increasing mean prey concentration, the ingestion rate of *A. granifera* feeding on *Pyramimonas* sp. increased rapidly, but slightly at the concentrations $\geq$306 ng C mL^{-1} (7,649 cells mL^{-1}). The maximum ingestion rate of *A. granifera* feeding on

Pyramimonas sp. was 0.97 ng C predator^{-1} d^{-1} (24.3 cells grazer^{-1}d^{-1}).

The calculated grazing coefficient for *A. granifera* feeding on co-occurring *Pyramimonas* sp. was up to 2.78 d^{-1}. The results of the present study suggest that *A. granifera* can sometimes have a considerable grazing impact on the population of *Pyramimonas* spp.

Finding feeding mechanism and grazing rate of new species through culture experiment, as done in this study, can be useful in predicting future changes in phytoplankton community near nuclear power plants.

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국문초록

원전 온배수 영향 해역 수온 상승에 대한 식물플랑크톤 군집의 반응 및 신규 기재 와편모류 종인 *Ansanella granifera*의 혼합영양 생태 연구

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지구 온난화 및 기후변화가 미래 해양 생태계에 미치는 영향을 원전 주변의 온배수 배출 환경을 이용하여 예측하고자 하였다. 2014년 말 기준 전 세계에는 437기의 원전이 가동되고 있다. 우리나라에는 현재 24기의 원전이 가동중이며, 복수기(condenser)를 거치는 해수의 수온은 약 7~9 ℃ 상승한다.

1999년부터 11년간 한빛원전과 한울원전 주변 각기 9개 정점 계절별 환경조사 자료에 의거하여 식물플랑크톤 군집에 미치는 온난화 영향을 분석하였다.

지구 온난화와 이로 인한 해양 수온 상승의 영향을 예측하기 위하여 (1) 온배수가 영향을 미치는 원전주변 해수의 물리화학적 특성을 파악하고 식물플랑크톤의 현존량과 생체량을 분석하였을 뿐만 아니라 (2) 계절별 기초 자료를 온도 상승 관점에서 분석하였다. (3) 이와 같은 해수 특성과 식물플랑크톤 군집 특성을 기초로 해양 생태계에 미치는 온도 상승 영향을 예측하였다.

1999년부터 2009년 사이에 한빛원전 주변해역은 2.4 ~ 37.6℃의 변화폭을 보인 반면 한울원전 주변해역은 7.8 ~ 30.2℃의 변화폭을 보였다. 한빛과 한울 원전주변 해역은 영양염류 농도, 투명도, 조류 유속 등의 물리화학적 특성뿐만 아니라 식물플랑크톤의 우점종 같은 생물학적 특성도 뚜렷한 차이를 보였다.

한빛 주변해역은 11℃와 32℃에서, 그리고 한울 주변해역은 14℃와 20℃에서 규조류 생체량 최대치를 나타내었다. 그러나 와편모류는 한빛 주변해역에서는 규조류보다 높은 온도인 14℃, 29℃와 35℃에서 생체량 최대치를 나타내었고, 한울의 경우는 14℃ 에서 20℃까지는 생체량이 늘어나다가 20℃ 이후에는 감소하였다.

클로로필 *a* 량으로 표현되는 소형 식물성플랑크톤은 한빛과 한울 주변해역에서 모두 11℃와 26~29℃에서 최대치가 나왔다. 식물플랑크톤 현존량이 높은 시기에는 소형(net) 플랑크톤의 기여도가 높았다. 그러나 저온이나 한빛의 경우 35℃ 이상의 고온 환경에서는 미소(nano) 플랑크톤의 기여도가 높았다.

수온 상승이 식물플랑크톤 현존량 변화에 항상 부정적인 영향을 나타내지는 않았다. 일반적으로 배수구의 식물플랑크톤 현존량이 취수구 현존량보다 낮았으나, 한빛원전의 경우 겨울철 배수구 정점은 취수구보다 현존량이 높게 나타나는 순기능을 보이기도 하였다. 한빛원전의 동계 배수구 수온 분포는 3.3 ~ 18.8 ℃이었다.

수온 변화에 따른 우점종의 출현양상을 고찰한 결과, 향후 지구온난화로 인한 수온 증가시 다른 식물플랑크톤보다 와편모류의 비중이 증가할 것으로 예상되며, 또한 광온성 및 고온적응형 플랑크톤이 늘어나게 될 것으로 기대된다.

본 연구 결과로 해양 생태계, 특히 식물플랑크톤의 현존량과 생체량에 미치는 온배수의 영향에 대한 이해를 높이고 지구 온난화에 따른 해양 식물플랑크톤 군집의 변화양상을 예측할 수 있다.

식물플랑크톤 중의 와편모류 비율은 미래 수온 상승기에 더욱 증가할 것으로 예측되므로 와편모류 특히 신종의 생태-생리적 특성을 밝히는 연구는 매우 중요한 일이다.

2010년 시화만에서 발견한 혼합영양식 와편모류 신종 *Ansanella granifera*의 성장과 관련한 생태-생리적 특성을 연구하였다. 혼합영양식 *A. granifera*의 섭식에 관하여 연구하기 위하여 섭식기작과 *A. granifera*가 섭식할 수 있는 종에 대해 연구하였다. 또한 유일한 먹이 조류인 *Pyramimonas* sp.의 농도분석을 통해 *A. granifera*의 성장률과 소화율을 측정하였다. *A. granifera*는 종속영양 박테리아와 *cyanobacterium Synechococcus* sp.도 섭식할 수 있다. 그러나 12종의 예상 먹이 조류로 실험해본 결과 *A. granifera*는 *Pyramimonas* sp.만을 소화할 수 있었다. *A. granifera*의 섭식방법은 먹이를 삼켜먹는 방식이었다(engulfment). 먹이 농도를 증가시키면 *A. granifera*의 성장률도 급격히 높아졌다. 그러나 먹이 농도가 434 ng C mL^{-1} (10,845 cells mL^{-1})에 이르면 성장률이 포화상태에 이르렀다. *Pyramimonas* sp.를 먹이로 제공했을 때의 *A. granifera*의 최대비성장률(즉 혼합영양 성장)은 20°C, 광도 20 μE m^{-2} s^{-1}에서 14:10의 낮밤주기일 때 1.426 d^{-1}이었다. 한편, 유사한 광조건에서 광영양 성장률은 0.391 d^{-1}이었다. 먹이 농도를 증가하면 *A. granifera*의 섭식률도 빠르게 증가하였다가 306 ng C mL^{-1} (7,649 cells mL^{-1}) 이상에서 줄어들었다. *Pyramimonas* sp.에 대한 *A. granifera*의 최대 섭식률은 0.97 ng C predator-1 d^{-1}(24.3 cells $grazer^{-1}$ d^{-1})이었다. *Pyramimonas* sp.에 대한 *A. granifera*의 포식계수는 2.78 d^{-1}로 계산되었다. 본 연구 결과 *A. granifera*는 *Pyramimonas* spp. 군집에 중요한 포식효과를 나타낼 수도 있을 것으로 판단된다. *A. granifera*에 대한 본 연구를 통해

혼합영양식 와편모류의 생태-생리적 특성과 해양 생태계 내 플랑크톤 먹이망에서의 와편모류 역할에 대한 이해를 제고하였다.

종합적으로, 본 연구 결과는 원전 주변해역 식물플랑크톤 군집 변화에 대한 이해뿐만 아니라 지구 온난화 지속시 해양 식물플랑크톤 군집의 변화 예측에도 적용할 수 있다.

주요어 : 삼킴, 섭식, 성장, 소화, 혼합영양, 원자력발전소, 식물플랑크톤, 온배수

학　　번 : 91312-806

Appendix

Appendix The maximum biomass(MB) and abundance(MA) of the top dominant species in Hanbit and Hanul NPP from 1999 to 2009

Table A-1. The maximum biomass(MB) and abundance(MA) of the top dominant species in Hanbit NPP from 1999 to 2009

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2000.02.07	W	C2	2.4	*Paralia sulcata*	0.4	7.92	7.7	1.4	27.0	10.64	0.18	7.61	37.2(31.2%)	74.4(28.1%)
2000.02.07	W	L2	2.7	*Ditylum brightwellii*	0.5	7.96	7.9	1.3	30.0	12.86	0.22	7.49	19.6(23.4%)	
				Cylindrotheca closterium										20.4(15.9%)
2000.02.07	W	R1	3.2	*Ditylum brightwellii*	0.5	8.03	7.2	1.9	28.0	11.57	0.24	6.96	29.3(25.4%)	
				Cylindrotheca closterium										40.8(20.0%)
2000.02.07	W	R2	3.2	*Paralia sulcata*	0.5	7.92	6.7	1.9	29.0	12.56	0.22	7.71	14.4(18.2%)	28.8(15.7%)
2005.02.03	W	ref	3.3	*Paralia sulcata*	0.2	8.10	9.6	0.9	35.3	6.69	0.19	1.85	14.4(47.6%)	28.8(51.4%)
1999.02.04	W	L2	3.4	*Paralia sulcata*	0.2	8.01	11.9	1.52	23	5.2	0.42	7.08	28.3(32.9%)	56.6(30.2%)
2004.02.10	W	C2	3.4	*Paralia sulcata*	0.2	8.05	11.3	1.5	69.4	13.11	0.49	1.59	20.9(52.0%)	41.8(54.0%)
2003.01.15	W	C2	3.6	*Paralia sulcata*	0.3	7.95	11.1	1.9	20.4	16.57	1.21	4.56	21.0(44.0%)	42.0(37.2%)
1999.02.04	W	R2	3.8	*Paralia sulcata*	0.2	7.96	10.9	1.45	21	5.5	0.61	4.78	44.6(42.5%)	89.2(30.1%)
2004.02.10	W	ref	3.9	*Paralia sulcata*	0.1	7.91	11.2	1.7	19.8	18.53	0.43	1.11	26.3(57.1%)	52.6(70.2%)
2008.02.19	W	C2	4.0	*Ditylum sol*	0.7	8.09	8.5	3.5	31.1		0.65	12.05	32.2(35.4%)	
				Eucampia zodiacus										71.0(38.4%)
2000.02.07	W	ref	4.1	*Plagiogramma vanheurckii*	0.4	7.86	7.0	1.3	27.0	13.33	0.21	7.10	15.6(22.2%)	
				Asterionellopsis kariana										37.2(18.0%)
2003.01.15	W	C1	4.1	*Paralia sulcata*	0.3	7.90	11.0	1.9	26.4	17.76	1.44	3.19	36.0(57.5%)	72.0(54.1%)
2003.01.15	W	L2	4.1	*Paralia sulcata*	0.3	7.98	10.8	1.2	19.7	19.46	1.11	1.32	31.0(48.5%)	62.1(60.3%)
2004.02.10	W	R2	4.1	*Thalassiosira sp.*	0.1	8.03	10.1	1.3	47.3	15.04	0.50	1.52	2.7(47.2%)	7.1(54.5%)
1999.02.04	W	C2	4.2	*Paralia sulcata*	0.2	7.93	11.0	2.23	24	6.6	0.59	6.63	57.3(57.1%)	114.6(45.2%)
2001.02.06	W	C2	4.2	*Thalassiosira rotula*	0.7	7.95	10.2	2.1	25.0	5.63	0.72	10.58	103.0(26.3%)	
				Paralia sulcata										198.0(22.9%)
2005.02.03	W	In	4.2	*Paralia sulcata*	0.2	8.12	9.1	1.3	8.4	7.96	0.25	2.85	34.3(61.0%)	68.6(52.7%)
1999.02.04	W	In	4.5	*Paralia sulcata*	0.1	8.02	11.0	1.7	23.0	3.49	0.30	5.38	35.4(39.1%)	70.8(30.3%)
2003.01.15	W	R2	4.5	*Paralia sulcata*	0.3	7.89	11.0	1.5	24.2	20.89	1.16	1.96	16.7(59.2%)	33.3(44.4%)
2005.02.03	W	C2	4.5	*Paralia sulcata*	0.3	8.09	9.5	1.1	49.6	10.15	0.29	3.17	10.7(37.1%)	21.4(47.6%)
2008.02.19	W	R2	4.5	*Thalassiosira rotula*	1.2	8.09	8.4	4.3	28.7		0.48	8.38	13.3(67.2%)	
				Chetoceros debilis										48.0(66.7%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L-1)	COD (mg L-1)	SS (mg L-1)	SiO_2 (umol L-1)	PO_4 (umol L-1)	NO_2+NO_3 (umol L-1)	Biomass (ng C mL-1)	Abundance (cells mL-1)
2005.02.03	W	R1	4.6	*Paralia sulcata*	0.2	8.13	9.4	0.8	30.2	7.07	0.45	4.37	54.6(67.3%)	109.1(50.9%)
1999.02.04	W	R1	4.7	*Paralia sulcata*	0.4	8.00	11.1	1.70	27	4.3	0.76	5.21	32.7(38.3%)	65.4(34.2%)
2000.02.07	W	L1	4.7	*Coscinodiscus gigas*	0.4	8.03	6.8	1.4	27.0	11.22	0.17	6.41	13.5(19.7%)	
				Cylindrotheca closterium										32.4(19.3%)
2003.01.15	W	In	4.7	*Paralia sulcata*	0.1	7.94	11.1	1.9	29.3	23.56	1.37	4.55	47.5(69.2%)	95.0(71.2%)
2003.01.15	W	L1	4.8	*Paralia sulcata*	0.2	7.91	11.0	1.7	20.7	21.41	1.45	3.33	12.8(49.3%)	25.6(48.2%)
2004.02.10	W	In	4.8	*Paralia sulcata*	0.1	8.04	11.0	1.6	37.8	11.01	0.53	2.27	29.8(80.0%)	59.7(85.9%)
2004.02.10	W	R1	4.8	*Thalassiosira sp.*	0.1	8.03	10.4	1.8	68.4	9.18	0.59	1.58	1.4(54.0%)	3.6(57.1%)
1999.02.04	W	ref	4.9	*Paralia sulcata*	0.3	8.06	11.1	2.2	21.0	3.00	0.56	4.81	48.6(43.3%)	97.2(28.9%)
2000.02.07	W	In	4.9	*Plagiogramma vanheurckii*	0.3	7.84	6.5	1.2	30.0	13.77	0.18	6.21	13.2(15.7%)	26.4(14.5%)
2009.02.02	W	L1	4.9	*Biddulphia mobiliensis*	0.4	8.21	10.3	4.1	19.9	0.76	0.31	0.89	93.5(41.0%)	
				Skeletonema costatum										428.0(36.3%)
2004.02.10	W	L2	5.0	*Protoperidinium brochii*	0.1	8.01	11.3	1.3	63.0	14.90	0.36	1.44	1.6(52.9%)	
				Thalassiosira sp.										3.7(83.3%)
2008.02.19	W	ref	5.0	*Ditylum sol*	0.5	8.03	9.1	4.2	53.7		0.47	7.58	128.9(58.0%)	
				Eucampia zodiacus										83.0(30.9%)
2009.02.02	W	ref	5.0	*Thalassiosira rotula*	0.4	8.09	9.9	4.4	30.1	1.43	0.34	2.48	79.2(21.4%)	
				Asterionellopsis glacialis										393.0(33.3%)
2000.02.07	W	C1	5.1	*Paralia sulcata*	0.4	7.85	7.4	1.6	32.0	12.25	0.17	6.72	24.6(27.2%)	49.2(22.2%)
2001.02.06	W	L2	5.1	*Paralia sulcata*	0.7	7.78	7.9	1.4	22.0	8.94	1.27	8.74	99.6(24.7%)	199.2(26.2%)
2009.02.02	W	In	5.2	*Eucampia zodiacus*	0.6	8.20	9.1	3.8	24.3	0.85	0.27	2.93	89.3(43.1%)	357.0(55.5%)
2001.02.06	W	In	5.4	*Paralia sulcata*	0.3	7.82	9.1	1.1	28.0	9.20	0.89	8.81	86.4(24.4%)	172.8(26.1%)
2003.01.15	W	ref	5.4	*Paralia sulcata*	0.2	7.89	10.7	1.6	27.8	21.48	1.15	3.28	40.5(63.8%)	81.1(64.5%)
2006.02.15	W	ref	5.5	*Pseudonitschia pungens*	0.3	8.00	13.0	2.0	35.3	9.12	0.55	3.80	6.0(24.6%)	12.0(21.7%)
2009.02.02	W	C1	5.5	*Eucampia zodiacus*	0.6	8.19	9.9	3.2	19.6	1.30	0.36	3.82	107.0(50.7%)	
				Asterionellopsis glacialis										464.0(39.4%)
2001.02.06	W	R1	5.6	*Ditylum brightwellii*	0.3	7.96	8.0	2.0	23.0	5.81	1.09	7.17	205.4(44.0%)	
				Paralia sulcata										181.2(26.0%)
2004.02.10	W	L1	5.6	*Protoperidinium sp.*	0.1	8.03	10.6	1.3	42.6	15.58	0.52	1.74	1.6(67.3%)	0.7(33.3%)
2006.02.15	W	C2	5.7	*Rhizosolenia setigera*	0.4	8.07	13.0	2.2	50.1	9.73	0.63	2.10	2.0(31.4%)	
				Skeletonema costatum										11.2(41.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2009.02.02	W	R2	5.8	*Ditylum sol*	0.3	8.19	10.1	4.2	17.8	0.62	0.25	1.77	193.3(44.6%)	
				Asterionellopsis glacialis										393.0(28.2%)
2004.02.10	W	C1	5.9	*Paralia sulcata*	0.1	7.97	9.9	1.0	67.5	13.75	0.63	2.19	23.6(57.5%)	47.3(66.7%)
2001.02.06	W	ref	6.0	*Ditylum brightwellii*	0.5	7.86	10.0	2.2	26.0	7.92	0.78	8.61	205.4(40.8%)	
				Paralia sulcata										187.2(24.6%)
2008.02.19	W	C1	6.0	*Thalassiosira rotula*	0.5	8.05	8.2	4.5	37.5		0.54	10.81	35.5(27.2%)	
				Paralia sulcata										65.0(25.4%)
2001.02.06	W	R2	6.1	*Paralia sulcata*	0.3	7.78	7.8	1.5	24.0	6.78	1.16	11.70	89.4(21.6%)	178.8(19.7%)
2009.02.02	W	L2	6.1	*Ditylum sol*	0.4	8.11	9.6	3.9	24.0	0.87	0.40	1.86	574.6(62.1%)	
				Eucampia zodiacus										643.0(39.1%)
2006.02.15	W	In	6.2	*Ditylum sol*	0.3	8.09	12.9	2.1	52.8	11.63	0.49	6.60	16.2(39.3%)	
				Pseudonitschia pungens										12.1(16.9%)
2009.02.02	W	C2	6.2	*Eucampia zodiacus*	0.8	8.21	10.1	3.8	19.2	0.57	0.22	2.67	642.5(92.8%)	2,570.0(84.7%)
2002.02.05	W	L2	6.3	*Paralia sulcata*	11.5	7.96	9.0	1.1	22.0	15.53	2.15	5.07	97.5(49.1%)	195.0(44.8%)
2001.02.06	W	L1	6.4	*Ditylum brightwellii*	0.3	7.92	8.8	0.9	23.0	5.58	0.13	7.15	176.0(38.9%)	
				Paralia sulcata										201.6(27.0%)
2008.02.19	W	L2	6.5	*Ditylum sol*	1.2	8.09	9.2	2.8	24.2		0.44	6.26	128.9(57.1%)	
				Thalassiosira rotula										60.0(31.3%)
2004.02.10	W	dis	6.6	*Paralia sulcata*	0.1	8.02	10.4	1.3	58.8	12.19	0.46	2.32	32.6(65.5%)	65.2(73.0%)
2006.02.15	W	R1	6.6	*Ditylum sol*	0.3	8.06	12.8	1.4	51.6	14.04	0.72	6.04	3.6(14.9%)	
				Skeletonema costatum										41.1(45.5%)
1999.02.04	W	dis	6.8	*Paralia sulcata*	0.3	7.94	11.0	2.1	22.0	4.60	0.55	6.50	37.6(41.8%)	75.2(25.4%)
2002.02.05	W	R2	6.9	*Paralia sulcata*	10.9	7.91	8.8	1.9	24.0	15.89	0.89	3.30	29.4(47.9%)	
				Thalassiosira decipiens										64.5(32.6%)
2006.02.15	W	L2	7.0	*Rhizosolenia setigera*	0.3	8.06	11.7	2.3	64.6	12.49	0.63	5.98	7.9(19.8%)	
				Skeletonema costatum										35.4(30.1%)
2008.02.19	W	R1	7.0	*Ditylum sol*	1.0	8.02	8.1	4.1	30.8		0.57	56.68	96.7(50.1%)	
				Skeletonema costatum										65.0(23.1%)
2005.02.03	W	L1	7.2	*Paralia sulcata*	0.2	8.10	9.7	1.1	64.4	7.33	0.24	3.68	37.6(74.6%)	75.2(65.0%)
2002.02.05	W	R1	7.4	*Paralia sulcata*	13.5	8.01	8.7	1.0	23.0	10.47	1.32	9.15	26.9(53.1%)	53.7(30.3%)
2002.02.05	W	ref	7.4	*Paralia sulcata*	10.2	7.98	8.9	1.4	26.0	16.72	1.74	5.64	19.5(25.7%)	39.0(20.5%)
2002.02.05	W	In	7.5	*Paralia sulcata*	14.5	7.96	8.8	1.7	28.0	16.55	1.84	6.65	66.7(51.4%)	133.4(45.5%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2006.02.15	W	L1	7.6	*Rhizosolenia setigera*	0.3	8.09	12.6	1.8	61.3	10.57	0.54	1.61	3.6(24.5%)	
				Skeletonema costatum										49.5(65.2%)
2009.02.02	W	R1	7.7	*Ditylum sol*	0.3	8.16	10.0	4.0	17.6	0.66	0.30	2.41	381.3(87.2%)	
				Asterionellopsis glacialis										250.0(36.8%)
2008.02.19	W	In	7.8	*Ditylum sol*	0.5	8.10	9.1	2.8	40.6		0.52	18.33	96.7(66.2%)	
				Eucampia zodiacus										60.0(33.3%)
1999.02.04	W	L1	7.9	*Paralia sulcata*	0.5	7.96	10.7	0.98	19	5.4	0.32	5.41	49.2(37.0%)	98.4(31.3%)
1999.02.04	W	C1	8.0	*Paralia sulcata*	0.3	8.04	10.5	2.26	23	5.0	0.17	5.78	55.9(47.0%)	111.8(31.7%)
2008.02.19	W	L1	8.0	*Ditylum sol*	0.7	8.08	8.5	3.3	35.6		0.54	6.27	64.4(35.0%)	
				Eucampia zodiacus										202.0(41.3%)
2003.01.15	W	R1	8.3	*Paralia sulcata*	0.2	7.87	10.4	1.4	22.9	22.20	1.33	4.65	53.0(70.7%)	106.0(72.6%)
2007.03.19	W	C2	8.4	*Eucampia zodiacus*	1.0	8.29	8.5	3.5	63.5	0.22	0.14	0.15	143.5(87.8%)	574.0(93.9%)
2002.02.05	W	L1	8.5	*Paralia sulcata*	17.9	7.99	8.0	1.9	23.0	12.75	2.46	4.13	90.9(53.4%)	181.8(44.2%)
2007.03.19	W	R2	8.9	*Eucampia zodiacus*	1.0	8.24	8.8	3.0	56.8	4.41	0.48	0.25	88.5(63.9%)	354.0(70.8%)
2002.02.05	W	C1	9.5	*Paralia sulcata*	14.1	8.04	8.3	1.4	26.0	15.93	2.05	4.36	40.9(56.1%)	81.8(37.5%)
2005.02.03	W	C1	9.5	*Paralia sulcata*	0.2	8.08	9.8	0.8	71.8	8.95	0.38	4.20	3.5(21.1%)	
				Skeletonema costatum										65.5(60.9%)
2007.03.19	W	ref	10.0	*Eucampia zodiacus*	0.9	8.18	8.1	3.0	57.3	5.35	0.39	3.84	102.8(65.9%)	411.0(71.4%)
2007.03.19	W	R1	10.1	*Eucampia zodiacus*	1.0	8.26	8.9	3.1	51.4	4.30	0.35	0.25	122.8(64.6%)	491.0(77.4%)
2007.03.19	W	In	10.2	*Eucampia zodiacus*	0.6	8.25	8.4	3.6	68.1	1.70	0.23	4.18	96.8(82.5%)	387.0(87.8%)
2007.03.19	W	L1	10.2	*Eucampia zodiacus*	0.9	8.27	8.4	3.9	65.2	1.71	0.26	2.69	131.8(60.3%)	527.0(75.2%)
2007.03.19	W	L2	10.2	*Eucampia zodiacus*	0.9	8.24	8.4	2.7	59.7	5.02	0.32	2.10	197.0(76.0%)	788.0(84.8%)
2002.02.05	W	C2	10.5	*Paralia sulcata*	13.7	7.90	8.1	1.6	25.0	16.41	2.28	9.38	15.7(27.9%)	
				Thalassiosira decipiens										78.3(41.7%)
2001.02.06	W	dis	10.6	*Ditylum brightwellii*	0.2	7.83	9.2	1.9	30.0	6.26	1.04	10.33	117.4(31.1%)	
				Paralia sulcata										207.6(30.4%)
2002.02.05	W	dis	10.8	*Paralia sulcata*	19.8	7.86	7.9	2.5	30.0	12.02	1.47	9.93	35.4(22.4%)	
				Thalassiosira decipiens										125.7(33.3%)
2000.02.07	W	dis	11.0	*Coscinodiscus asteromphalus*	0.3	7.88	7.0	1.4	28.0	12.76	0.26	7.21	29.0(25.3%)	
				Asterionella kariana										21.6(10.3%)
2001.02.06	W	C1	11.3	*Paralia sulcata*	0.3	7.98	8.2	1.8	26.0	6.12	0.97	8.54	127.8(36.3%)	255.6(25.3%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2005.04.12	Sp	C2	11.7	*Paralia sulcata*	0.3	8.02	9.8	1.0	53.8	4.37	0.31	1.84	13.3(31.9%)	26.7(22.2%)
2002.11.05	A	In	12.2	*Thalassiosira decipiens*	0.1	7.91	8.9	1.4	51.0	14.94	0.74	7.98	534.8(85.1%)	2,660.5(70.5%)
2002.11.05	A	ref	12.2	*Thalassiosira decipiens*	0.2	7.91	10.0	1.3	34.0	11.39	0.42	9.16	634.3(88.2%)	3,155.7(82.9%)
2002.11.05	A	C2	12.3	*Thalassiosira decipiens*	0.1	7.90	8.7	0.9	49.0	14.20	0.21	9.37	487.2(57.3%)	2,423.9(64.4%)
2002.11.05	A	L1	12.3	*Thalassiosira decipiens*	0.2	7.92	8.9	1.2	43.0	19.92	0.68	5.52	570.4(84.7%)	2,837.9(71.9%)
2002.11.05	A	L2	12.3	*Thalassiosira decipiens*	0.2	7.80	9.7	0.9	56.0	17.41	0.23	9.06	384.1(66.4%)	1,911.1(67.7%)
2002.11.05	A	R2	12.4	*Thalassiosira decipiens*	0.2	7.94	9.7	1.4	74.0	19.53	0.61	11.21	392.9(59.2%)	1,954.8(62.3%)
2004.04.13	Sp	C2	12.5	*Eucampia zodiacus*	1.2	8.05	7.2	0.9	23.6	2.88	0.11	0.83	3.4(41.8%)	13.8(43.8%)
2005.02.03	W	dis	12.5	*Plagiogramma vanheurckii*	0.1	8.05	9.4	1.7	90.3	5.91	0.32	2.43	14.4(33.9%)	28.8(38.7%)
1999.04.20	Sp	C2	12.6	*Paralia sulcata*	0.6	8.11	15.9	2.08	19	8.4	0.31	5.12	175.2(58.6%)	350.4(42.1%)
2003.04.15	Sp	C2	12.9	*Paralia sulcata*	1.5	8.20	9.0	2.3	6.0	4.94	0.19	1.02	2.9(29.7%)	5.7(25.0%)
2007.03.19	W	C1	12.9	*Eucampia zodiacus*	0.8	8.24	8.5	3.3	70.4	6.44	0.42	5.75	39.5(52.4%)	158.0(56.0%)
2002.11.05	A	C1	13.0	*Thalassiosira decipiens*	0.2	7.93	9.2	1.5	38.0	15.15	0.79	9.72	444.1(76.8%)	2,209.7(70.3%)
2003.01.15	W	dis	13.1	*Paralia sulcata*	0.1	7.92	10.8	2.1	31.1	20.37	1.28	3.95	72.9(75.7%)	145.7(76.4%)
2004.04.13	Sp	L1	13.1	*Ditylum brightwellii*	1.5	8.08	8.2	0.5	13.2	3.61	0.37	0.80	15.5(35.4%)	
				Eucampia zodiacus										9.5(17.2%)
2006.11.16	A	ref	13.1	*Paralia sulcata*	0.4	8.07	7.6	0.6	53.8	14.04	0.35	10.42	12.0(47.6%)	24.0(41.4%)
2009.02.02	W	dis	13.2	*Asterionellopsis glacialis*	0.2	8.11	9.6	4.0	25.0	1.17	0.24	2.69	58.9(64.6%)	464.0(52.0%)
2003.04.15	Sp	R2	13.3	*Paralia sulcata*	1.9	8.26	8.5	2.2	6.2	4.78	0.21	0.93	1.0(12.8%)	
				Cylindrotheca closterium										6.0(25.9%)
2004.04.13	Sp	R2	13.3	*Cerataulina pelagica*	1.9	8.16	8.1	0.5	9.1	2.66	0.08	0.88	179.7(83.9%)	309.8(74.2%)
2006.02.15	W	C1	13.3	*Ditylum sol*	0.3	8.02	10.8	2.0	55.3	12.61	0.49	4.30	5.4(34.0%)	
				Skeletonema costatum										12.1(30.8%)
2003.04.15	Sp	ref	13.4	*unid. Dinoflagellates*	0.6	8.22	8.9	1.6	8.2	6.91	0.22	0.92	5.4(20.3%)	
				Cylindrotheca closterium										34.8(39.9%)
1999.04.20	Sp	L2	13.5	*Paralia sulcata*	0.6	8.04	13.8	2.01	18	11.1	0.22	5.80	291.0(52.8%)	582.0(43.4%)
2002.11.05	A	R1	13.5	*Thalassiosira decipiens*	0.2	7.90	9.7	1.0	36.0	18.27	0.52	5.84	497.9(83.5%)	2,477.3(72.7%)
2006.11.16	A	C2	13.5	*Paralia sulcata*	0.4	8.18	7.5	0.9	13.8	11.82	0.59	8.77	19.0(59.4%)	38.0(41.8%)
2009.05.09	Sp	ref	13.5	*Gyrodinium spirale*	0.6	8.35	7.7	2.4	20.7	4.18	0.32	3.38	18.0(67.2%)	
				chroomonas sp.										393.0(84.5%)
2005.04.12	Sp	L1	13.6	*Paralia sulcata*	0.3	8.06	8.3	1.2	35.4	3.55	0.29	3.18	38.3(54.8%)	76.6(47.6%)
2005.04.12	Sp	R1	13.6	*Paralia sulcata*	0.2	8.06	7.8	1.6	35.9	3.01	0.44	3.26	28.9(35.9%)	57.8(24.6%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2003.04.15	Sp	L2	13.8	*Paralia sulcata*	1.5	8.30	8.9	1.8	7.9	8.46	0.15	3.24	2.1(28.0%)	
				Cylindrotheca closterium										11.4(44.4%)
2004.04.13	Sp	L2	13.8	*Protoperidinium sp.*	1.0	8.10	8.2	0.5	10.0	4.25	0.24	0.78	4.2(25.7%)	
				Eucampia zodiacus										7.6(28.6%)
2005.04.12	Sp	In	13.9	*Paralia sulcata*	0.3	8.06	8.8	1.6	24.0	7.03	0.42	3.15	31.7(51.5%)	63.4(46.4%)
2006.11.16	A	C1	14.0	*Paralia sulcata*	0.4	8.16	7.5	0.6	31.9	11.70	0.49	9.83	24.0(42.0%)	48.0(40.0%)
2006.11.16	A	L1	14.1	*Paralia sulcata*	0.4	8.15	7.5	0.7	33.6	17.85	0.45	7.88	13.5(47.0%)	27.0(28.1%)
2004.04.13	Sp	In	14.2	*Paralia sulcata*	0.9	8.16	8.8	0.7	13.6	2.21	0.13	0.86	12.4(47.6%)	24.7(39.1%)
2006.11.16	A	In	14.3	*Paralia sulcata*	0.4	8.17	7.2	0.9	19.1	13.91	0.72	10.45	40.0(62.1%)	80.0(47.1%)
2002.04.18	Sp	R2	14.4	*Paralia sulcata*	0.4	8.21	8.0	1.9	24.0	15.06	0.01	6.07	301.2(48.5%)	602.4(45.8%)
2004.04.13	Sp	ref	14.4	*Protoperidinium sp.*	1.0	8.18	8.3	0.5	13.7	3.96	0.14	0.85	10.8(43.9%)	
				Cylindrotheca closterium										14.9(28.3%)
2001.04.24	Sp	C2	14.5	*Paralia sulcata*	1.0	7.83	8.8	1.8	25.0	1.84	0.24	1.39	108.0(25.5%)	216.0(24.7%)
2002.04.18	Sp	In	14.5	*Paralia sulcata*	0.2	8.18	7.9	2.0	61.0	17.93	0.22	5.35	385.4(44.0%)	770.8(38.9%)
2002.04.18	Sp	R1	14.6	*Paralia sulcata*	0.2	8.17	8.0	2.0	48.0	17.87	0.80	11.70	255.4(29.8%)	510.8(30.3%)
2006.02.15	W	dis	14.6	*Ditylum sol*	0.2	8.03	10.6	1.6	75.5	11.41	0.69	6.64	5.1(27.7%)	
				Rhizosolenia setigera										5.7(19.0%)
1999.04.20	Sp	R2	14.7	*Paralia sulcata*	0.6	7.92	14.1	1.51	22	10.6	0.29	4.80	226.2(53.1%)	452.4(41.7%)
1999.04.20	Sp	In	14.8	*Paralia sulcata*	0.5	8.06	15.3	2.2	19.0	9.90	0.34	6.19	180.0(51.4%)	360.0(38.9%)
1999.04.20	Sp	R1	14.8	*Paralia sulcata*	0.7	7.97	13.5	0.90	20	10.9	0.30	6.12	155.4(47.1%)	310.8(36.1%)
2003.04.15	Sp	In	14.8	*Scenedesmus sp.*	1.0	8.15	8.5	2.2	5.7	11.81	1.36	1.26	3.9(17.7%)	
				Cylindrotheca closterium										21.9(25.9%)
1999.04.20	Sp	ref	14.9	*Paralia sulcata*	0.8	8.01	14.0	2.9	17.0	10.19	0.48	5.87	208.2(55.9%)	416.4(42.6%)
2001.04.24	Sp	R2	14.9	*Ditylum brightwellii*	1.0	7.80	8.0	1.5	27.0	1.79	0.63	1.61	136.9(33.0%)	
				Paralia sulcata										88.8(13.3%)
2001.04.24	Sp	L2	15.0	*Prorocentrum micans*	0.6	7.90	9.2	1.1	30.0	2.23	0.16	2.67	40.8(16.9%)	
				Rhizosolenia delicatula										146.4(21.9%)
2002.04.18	Sp	ref	15.0	*Paralia sulcata*	0.3	8.27	7.5	1.6	31.0	15.89	0.19	9.29	425.1(68.4%)	850.2(48.6%)
2003.04.15	Sp	R1	15.0	*Coscinodiscus radiatus*	1.4	8.25	8.7	1.8	7.9	7.13	0.19	0.96	1.9(12.9%)	
				Cylindrotheca closterium										24.2(49.2%)
2001.04.24	Sp	ref	15.1	*Prorocentrum micans*	0.6	7.95	8.6	1.9	33.0	1.52	0.14	2.65	81.6(25.6%)	
				Paralia sulcata										112.8(16.6%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L-1)	COD (mg L-1)	SS (mg L-1)	SiO_2 (umol L-1)	PO_4 (umol L-1)	NO_2+NO_3 (umol L-1)	Biomass (ng C mL-1)	Abundance (cells mL-1)
2003.04.15	Sp	L1	15.1	*centric diatoms*	1.0	8.23	8.1	1.8	5.9	20.87	0.53	1.16	2.5(16.7%)	
				Cylindrotheca closterium										12.7(22.0%)
2009.05.09	Sp	C2	15.1	*Bacteriastrum hyalinum*	1.2	8.34	7.2	3.3	20.5	1.97	0.32	5.39	18.0(72.5%)	
				chroomonas sp.										107.0(59.8%)
2002.04.18	Sp	C2	15.2	*Paralia sulcata*	0.5	8.19	7.8	1.5	28.0	17.50	0.21	11.84	126.7(29.1%)	
				Thalassiosira decipiens										304.1(24.0%)
2002.04.18	Sp	L1	15.2	*Paralia sulcata*	0.4	8.05	7.6	2.3	35.0	18.15	1.00	6.19	178.4(26.8%)	356.8(28.0%)
2002.04.18	Sp	L2	15.2	*Paralia sulcata*	0.2	8.17	7.7	2.1	72.0	18.00	0.00	4.35	378.9(50.2%)	757.8(40.0%)
2003.04.15	Sp	C1	15.2	*Paralia sulcata*	1.1	8.24	8.4	2.2	6.1	6.40	0.24	1.01	4.3(15.7%)	
				Cylindrotheca closterium										57.0(49.2%)
2007.11.05	A	C2	15.2	*Rhizosolenia alata form a gracillima*	1.0	8.21	6.9	1.7	19.1	2.42	0.09	2.82	217.1(87.8%)	446.0(84.2%)
2009.05.09	Sp	In	15.3	*Chaetoceros pseudocrinitus*	0.5	8.36	7.4	2.7	26.7	5.05	0.43	6.54	17.1(76.7%)	
				chroomonas sp.										214.0(54.5%)
2007.11.05	A	ref	15.4	*Rhizosolenia alata form a gracillima*	1.0	8.21	7.4	3.4	21.9	5.82	0.32	7.61	34.6(55.3%)	71.0(54.2%)
2004.04.13	Sp	R1	15.5	*Protoperidinium sp.*	1.8	7.99	7.9	0.7	13.1	2.44	0.30	0.79	1.0(13.3%)	
				Eucampia zodiacus										2.4(20.9%)
2008.02.19	W	dis	15.5	*Ditylum sol*	0.7	8.04	8.2	4.0	41.3		0.58	11.88	64.4(57.3%)	
				Skeletonema costatum										24.0(21.1%)
2009.05.09	Sp	L1	15.5	*Coscinodiscus sp.*	0.8	8.35	7.4	3.5	33.8	2.58	0.37	3.23	58.0(96.4%)	
				chroomonas sp.										107.0(74.8%)
2009.05.09	Sp	L2	15.5	*Paralia sulcata*	0.8	8.34	7.3	3.3	23.0	4.86	0.31	3.80	71.5(91.7%)	143.0(50.0%)
2000.10.31	A	R2	15.8	*Paralia sulcata*	0.4	8.23	7.2	1.6	29.0	9.78	0.25	5.65	24.6(23.2%)	49.2(24.9%)
2007.11.05	A	L2	15.9	*Rhizosolenia alata form a gracillima*	1.0	8.20	7.2	2.9	22.4	5.35	0.31	10.41	75.4(77.8%)	155.0(83.8%)
2002.04.18	Sp	C1	16.0	*Paralia sulcata*	0.3	8.07	7.5	2.3	49.0	18.02	0.06	6.55	276.1(36.1%)	552.1(33.3%)
2000.10.31	A	C2	16.2	*Paralia sulcata*	0.2	8.27	6.9	1.1	23.0	11.14	0.24	5.88	37.8(33.8%)	75.6(29.2%)
2000.10.31	A	In	16.2	*Pleurosigma elongatum*	0.2	8.26	6.8	1.4	30.0	10.24	0.20	5.60	18.0(19.4%)	
				Thalassiosira decipiens										43.2(20.8%)
2009.05.09	Sp	R2	16.2	*Myrionecta rubra*	1.0	8.29	7.1	3.3	23.3	1.62	0.29	4.07	18.0(60.8%)	
				chroomonas sp.										107.0(42.8%)
2004.11.04	A	ref	16.3	*Paralia sulcata*	0.4	7.87	7.8	1.9	10.6	11.01	1.46	5.58	188.3(71.5%)	376.7(57.1%)
2005.04.12	Sp	ref	16.3	*Paralia sulcata*	0.3	7.87	7.8	1.0	61.3	5.96	0.16	2.18	79.0(71.4%)	158.0(52.5%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L-1)	COD (mg L-1)	SS (mg L-1)	SiO_2 (umol L-1)	PO_4 (umol L-1)	NO_2+NO_3 (umol L-1)	Biomass (ng C mL-1)	Abundance (cells mL-1)
2005.11.01	A	C2	16.3	*Paralia sulcata*	0.3	8.14	8.1	1.1	25.1	14.82	0.49	4.74	17.5(75.3%)	35.0(71.4%)
2007.11.05	A	In	16.3	*Rhizosolenia alata form a gracillima*	1.0	8.18	6.3	4.0	27.1	5.64	0.52	5.74	72.5(66.3%)	149.0(78.0%)
2009.05.09	Sp	R1	16.3	*Dictyocha fibula*	1.2	8.31	7.1	3.2	24.3	1.97	0.29	4.45	19.8(58.5%)	
				chroomonas sp.										143.0(57.0%)
2001.04.24	Sp	R1	16.4	*Paralia sulcata*	0.9	7.86	8.1	1.8	30.0	1.37	0.29	2.66	84.6(18.5%)	169.2(20.9%)
2007.11.05	A	L1	16.4	*Rhizosolenia alata form a gracillima*	1.0	8.19	6.7	3.0	22.5	4.76	0.30	5.73	84.2(55.6%)	173.0(70.6%)
2004.11.04	A	R2	16.5	*Euglena sp.*	0.7	8.11	7.7	2.0	11.1	9.79	1.16	4.74	10.2(41.2%)	37.6(40.0%)
2007.05.07	Sp	ref	16.5	*Paralia sulcata*	1.0	8.20	7.9	1.9	45.8	17.98	0.85	18.15	34.5(58.9%)	69.0(33.8%)
2008.05.13	Sp	C2	16.5	*Chaetoceros pendulus*	3.1	7.90	6.7	4.1	20.5		0.13	0.64	0.7(85.7%)	
				chroomonas sp.										6.0(50.0%)
2000.10.31	A	ref	16.6	*Paralia sulcata*	0.3	8.42	6.7	1.8	28.0	9.49	0.26	5.84	18.0(21.0%)	36.0(16.9%)
2000.10.31	A	R1	16.7	*Paralia sulcata*	0.3	8.12	6.6	1.7	18.0	10.80	0.24	5.65	39.0(38.6%)	78.0(28.0%)
1999.04.20	Sp	C1	16.8	*Paralia sulcata*	0.5	7.95	11.2	2.47	21	9.7	0.28	4.78	210.6(62.5%)	421.2(48.8%)
2001.04.24	Sp	In	16.9	*Prorocentrum micans*	0.6	7.92	8.4	2.1	29.0	2.84	0.32	2.86	74.4(22.0%)	
				Paralia sulcata										118.8(18.0%)
2005.11.01	A	In	16.9	*Paralia sulcata*	0.2	8.10	7.8	1.4	62.1	23.28	0.49	3.39	145.0(70.3%)	290.0(70.2%)
2007.11.05	A	C1	16.9	*Rhizosolenia alata form a gracillima*	0.6	8.20	7.2	0.6	20.8	3.40	0.24	5.33	234.6(97.5%)	482.0(96.4%)
2000.05.03	Sp	C2	17.0	*Paralia sulcata*	1.1	8.02	6.6	1.5	31.0	12.55	0.31	7.01	66.0(25.6%)	132.0(25.8%)
2000.10.31	A	L1	17.0	*Ditylum brightwellii*	0.3	8.30	7.0	1.9	42.0	10.06	0.26	5.22	19.6(24.0%)	
				Pleurosigma elongatum										27.6(17.6%)
2004.11.04	A	C2	17.0	*Ditylum sol*	0.9	8.00	7.6	1.7	8.7	8.48	0.73	4.58	182.0(30.5%)	
				Paralia sulcata										271.1(32.0%)
2004.11.04	A	R1	17.0	*Ceratium kofoidii*	0.7	8.13	7.7	2.0	6.2	15.09	0.84	4.95	47.5(34.1%)	
				Thalassiosira sp. 1										94.9(38.5%)
2005.11.01	A	R1	17.0	*Paralia sulcata*	0.2	8.13	8.0	1.8	39.1	8.62	0.50	5.71	32.5(80.9%)	65.0(84.4%)
2008.05.13	Sp	ref	17.0	*Scrippsiella trochoidea*	2.0	7.95	7.7	3.4	20.7		0.22	2.00	4.0(28.7%)	
				Cylindrotheca closterium										18.0(21.4%)
2004.11.04	A	L2	17.1	*Paralia sulcata*	0.5	7.96	7.7	1.7	12.3	16.08	1.49	2.66	166.7(68.7%)	333.5(59.4%)
2005.11.01	A	ref	17.1	*Paralia sulcata*	0.2	8.16	8.0	1.5	36.5	22.77	0.52	3.85	59.5(81.0%)	119.0(82.1%)
2001.04.24	Sp	C1	17.2	*Prorocentrum micans*	1.0	7.95	7.9	1.6	27.0	2.41	0.04	2.12	93.6(26.3%)	
				Paralia sulcata										135.6(25.6%)
2006.11.16	A	R1	17.2	*Paralia sulcata*	0.1	8.12	7.0	0.8	43.4	18.79	0.65	9.41	13.5(58.3%)	27.0(44.3%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2007.11.05	A	R2	17.2	*Rhizosolenia alata form a gracillima*	0.4	8.18	7.2	3.1	22.1	3.57	0.24	2.82	153.3(84.7%)	315.0(84.0%)
2008.05.13	Sp	R2	17.3	*Gymnodinium sp.*	1.4	7.86	7.5	3.6	23.3		0.32	0.89	27.0(61.4%)	54.0(32.1%)
2000.05.03	Sp	L2	17.4	*Coscinodiscus concinnus*	0.7	8.03	7.1	1.6	29.0	9.75	0.33	6.75	31.0(15.0%)	
				Asterionellopsis glacialis										48.0(11.8%)
2005.11.01	A	C1	17.4	*Paralia sulcata*	0.2	8.16	7.4	1.4	32.9	19.71	0.51	5.37	20.5(70.7%)	41.0(67.2%)
2005.11.01	A	L1	17.4	*Paralia sulcata*	0.2	8.13	7.9	1.7	50.1	13.38	0.50	4.62	30.0(79.2%)	60.0(78.9%)
2006.05.07	Sp	ref	17.4	*Navicula sp.*	1.2	8.08	8.8	1.9	8.0	1.39	0.45	3.53	15.0(29.3%)	
				Skeletonema costatum										43.2(24.7%)
2001.04.24	Sp	L1	17.5	*Paralia sulcata*	1.0	7.83	8.0	2.1	26.0	2.61	0.12	4.14	67.2(28.0%)	134.4(23.7%)
2004.11.04	A	In	17.5	*Paralia sulcata*	0.3	8.10	8.2	2.2	34.0	16.69	0.76	4.65	93.1(89.2%)	186.1(79.2%)
2007.05.07	Sp	L2	17.5	*Alexandrium sp.*	1.0	8.24	7.9	2.4	44.2	16.04	0.81	9.85	13.8(34.1%)	
				Thalassionema nitzschioides										27.0(24.3%)
2008.05.13	Sp	C1	17.5	*Paralia sulcata*	1.0	7.82	6.6	4.1	22.9		0.34	3.16	21.0(39.0%)	42.0(20.0%)
2004.11.04	A	L1	17.6	*Paralia sulcata*	0.4	8.14	8.4	2.3	25.4	7.33	1.17	4.29	8.7(22.3%)	
				Chetoceros debilis										34.9(33.3%)
2006.05.07	Sp	In	17.6	*Navicula sp.*	0.9	8.09	9.0	1.7	11.9	1.84	0.41	7.32	26.9(44.7%)	
				Skeletonema costatum										59.8(21.7%)
2000.05.03	Sp	R2	17.7	*Paralia sulcata*	0.7	8.02	6.1	1.8	31.0	10.32	0.32	8.48	61.2(30.6%)	122.4(26.0%)
2007.05.07	Sp	In	17.7	*Paralia sulcata*	1.2	8.22	7.8	1.4	38.7	15.94	0.92	13.43	20.0(29.9%)	40.0(37.0%)
2006.05.07	Sp	L1	17.8	*Navicula sp.*	1.1	8.10	9.0	1.4	11.4	0.30	0.49	6.13	16.8(37.2%)	
				Cylindrotheca closterium										34.0(16.1%)
2007.05.07	Sp	L1	17.8	*Alexandrium sp.*	1.0	8.23	7.8	3.7	51.5	7.81	0.60	4.72	13.8(39.7%)	
				chroomonas sp.										42.0(37.8%)
2000.05.03	Sp	ref	17.9	*Ditylum brightwellii*	0.5	8.02	6.2	1.7	33.0	12.23	0.25	8.11	156.5(47.7%)	
				Paralia sulcata										121.2(20.2%)
2003.10.21	A	In	18.2	*Chaetoceros debilis*	1.0	7.96	8.5	1.4	10.8	9.07	0.36	3.43	4.5(14.0%)	37.7(37.9%)
2000.05.03	Sp	R1	18.3	*Plagiogramma vanheurckii*	0.5	8.00	6.0	1.6	28.0	11.31	0.36	7.63	73.2(25.9%)	146.4(20.4%)
2007.05.07	Sp	R2	18.3	*Gymnodinium sp.*	1.0	8.28	7.5	3.4	39.7	12.86	0.72	0.47	19.5(31.8%)	
				chroomonas sp.										586.0(84.8%)
2008.05.13	Sp	L2	18.3	*Paralia sulcata*	2.2	7.91	7.0	4.8	23.0		0.24	0.98	15.0(44.6%)	
				Skeletonema costatum										36.0(27.3%)
2000.10.31	A	L2	18.4	*Pleurosigma elongatum*	0.4	8.19	7.1	1.3	15.0	9.68	0.24	5.42	13.2(19.7%)	26.4(13.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2003.10.21	A	R1	18.4	*Scrippsiella trochoidea*	1.4	7.97	8.5	1.2	9.5	8.16	0.62	3.36	16.2(41.7%)	24.2(28.8%)
2007.05.07	Sp	R1	18.5	*Paralia sulcata*	1.0	8.27	7.5	2.9	43.3	14.90	0.97	0.55	44.5(56.6%)	89.0(56.3%)
2009.10.21	A	L1	18.5	*Gonyaulax polygramma*	0.3	7.89	6.8	3.6	23.3	19.40	0.84	11.67	10.1(50.0%)	
				Cylindrotheca closterium										12.0(28.6%)
1999.04.20	Sp	L1	18.6	*Paralia sulcata*	0.6	8.03	12.3	1.51	21	9.5	0.25	5.32	91.8(27.1%)	
				Thalassiosira decipiens										370.8(38.1%)
2000.05.03	Sp	In	18.6	*Paralia sulcata*	0.4	8.07	6.3	1.4	30.0	11.59	0.28	7.58	32.4(13.5%)	
				Asterionellopsis glacialis										74.7(11.2%)
2001.11.07	A	R2	18.6	*Ditylum brightwellii*	0.3	8.18	7.0	1.9	10.0	15.23	0.52	10.92	39.1(24.8%)	
				Thalassiosira rotula										51.6(20.7%)
2003.10.21	A	C1	18.6	*Guinardia flaccida*	1.1	7.96	8.6	1.3	10.1	8.59	0.20	3.83	4.3(19.0%)	
				Chaetoceros pseudocrinitus										6.8(16.0%)
2003.10.21	A	L1	18.6	*Paralia sulcata*	1.0	8.00	8.7	1.4	9.8	10.76	0.44	3.47	4.8(32.8%)	9.6(25.4%)
2009.10.21	A	C2	18.6	*Myrionecta rubra*	0.3	7.90	6.8	3.6	19.8	8.53	0.59	7.61	6.0(73.5%)	
				Chroomonas sp.										36.0(60.0%)
2001.11.07	A	C2	18.7	*Thalassiosira rotula*	0.7	8.07	6.3	1.8	11.0	13.81	0.44	11.98	41.7(28.8%)	56.4(19.0%)
2001.11.07	A	L2	18.7	*Ditylum brightwellii*	0.4	7.93	7.3	2.2	12.0	14.67	0.55	10.97	58.7(32.6%)	
				Thalassiosira rotula										61.2(19.1%)
2003.10.21	A	ref	18.7	*Rhizosolenia setigera*	0.6	7.93	8.2	0.8	10.3	11.45	0.30	3.07	437.4(94.5%)	568.0(90.3%)
2008.05.13	Sp	L1	18.7	*Gymnodinium sp.*	1.0	7.87	6.8	3.1	33.8		0.32	0.76	24.0(60.3%)	48.0(36.4%)
2009.10.21	A	ref	18.7	*Coscinodiscus sp.*	0.2	7.91	7.0	5.0	59.4	17.00	0.77	18.11	9.7(49.5%)	
				Pleurosigma elongatum										6.0(16.7%)
2003.10.21	A	L2	18.8	*Chaetoceros debilis*	1.5	7.90	9.2	1.4	7.3	8.52	0.33	2.69	12.8(40.3%)	107.2(66.2%)
2007.03.19	W	dis	18.8	*Eucampia zodiacus*	0.2	8.15	8.3	4.0	80.6	4.68	0.44	2.97	122.0(75.5%)	488.0(79.9%)
2008.05.13	Sp	In	18.8	*Gymnodinium sp.*	0.5	7.88	7.0	3.4	26.7		0.26	0.99	27.0(92.0%)	54.0(45.0%)
2009.10.21	A	In	18.8	*Paralia sulcata*	0.3	7.87	6.8	1.9	21.7	26.35	0.97	14.38	12.0(73.2%)	24.0(50.0%)
2000.10.31	A	C1	19.0	*Paralia sulcata*	0.3	8.37	6.8	2.0	20.0	9.76	0.24	6.39	18.6(25.7%)	37.2(23.1%)
2002.11.05	A	dis	19.0	*Thalassiosira decipiens*	0.1	7.83	8.8	1.6	60.0	22.78	0.44	7.75	411.8(76.8%)	2048.9(67.9%)
2008.05.13	Sp	R1	19.0	*Gymnodinium sp.*	1.6	7.86	7.5	5.4	24.3		0.24	1.45	15.0(41.1%)	
				Chroomonas sp.										48.0(29.6%)
2009.10.21	A	L2	19.0	*Paralia sulcata*	0.3	7.90	7.0	3.9	24.2	17.96	0.86	17.33	12.0(79.2%)	24.0(66.7%)
2009.10.21	A	C1	19.1	*Paralia sulcata*	0.2	7.87	6.8	1.8	27.5	13.15	0.89	17.52	21.0(34.2%)	42.0(50.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2001.11.07	A	ref	19.3	*Thalassiosira rotula*	0.5	8.13	6.4	0.5	13.0	18.29	0.66	12.36	38.2(36.3%)	51.6(17.9%)
2004.04.13	Sp	C1	19.3	*Ceratium fusus*	1.2	7.88	7.7	0.8	11.1	2.90	0.21	0.83	2.2(21.5%)	
				Chaetoceros sp.										3.8(16.2%)
2007.05.07	Sp	C1	19.4	*Gymnodinium sp.*	1.0	8.22	7.7	4.1	48.9	14.33	0.75	10.61	62.5(49.2%)	
				Chroomonas sp.										821.0(80.6%)
2007.11.05	A	R1	19.4	*Paralia sulcata*	0.4	8.14	7.1	1.9	26.9	5.95	0.40	7.06	68.5(55.0%)	137.0(54.8%)
2009.10.21	A	R2	19.4	*Dinophysis caudata*	0.5	7.90	6.9	1.6	18.7	13.42	0.65	19.91	15.8(73.6%)	
				Skeletonema costatum										30.0(50.0%)
2000.05.03	Sp	L1	19.5	*Paralia sulcata*	0.8	8.04	6.6	1.1	30.0	10.77	0.30	6.26	43.2(25.3%)	86.4(20.9%)
2006.05.07	Sp	C2	19.5	*Navicula sp.*	1.8	8.10	8.5	1.6	6.1	0.21	0.35	2.10	4.9(25.6%)	
				Skeletonema costatum										64.2(52.1%)
2003.10.21	A	C2	19.6	*Scrippsiella trochoidea*	1.5	7.93	8.9	0.9	13.1	9.74	0.30	2.98	22.2(62.7%)	33.1(35.8%)
2007.05.07	Sp	C2	19.6	*Gymnodinium sp.*	1.0	8.22	7.7	2.4	43.9	9.45	0.70	0.75	21.0(38.7%)	
				Chroomonas sp.										271.0(72.7%)
2001.11.07	A	In	19.7	*Thalassiosira rotula*	0.6	8.19	7.1	1.8	11.0	21.22	0.69	14.56	34.6(22.7%)	46.8(20.2%)
2001.11.07	A	L1	19.7	*Ditylum brightwellii*	0.6	8.15	6.9	2.4	10.0	26.73	0.58	20.28	29.3(27.0%)	
				Skeletonema costatum										73.2(26.2%)
2006.05.07	Sp	C1	19.7	*Navicula sp.*	1.5	8.08	8.8	1.3	9.6	0.41	0.19	2.42	3.8(19.2%)	
				Skeletonema costatum										35.2(32.0%)
2003.10.21	A	R2	19.8	*Gymnodinium sp.*	1.9	7.90	8.7	0.8	8.5	6.91	0.24	3.42	7.1(20.8%)	
				Chaetoceros debilis										23.3(28.5%)
1999.04.20	Sp	dis	20.0	*Paralia sulcata*	0.4	8.10	11.0	2.7	23.0	10.85	0.58	5.14	226.0(35.1%)	452.0(36.5%)
2004.11.04	A	C1	20.0	*Paralia sulcata*	0.1	8.11	8.0	1.6	97.1	12.77	1.25	3.78	158.4(77.5%)	316.7(41.7%)
2009.05.09	Sp	C1	20.2	*Paralia sulcata*	0.6	8.25	7.2	3.1	22.9	2.92	0.30	5.39	89.5(93.3%)	179.0(55.6%)
2006.05.07	Sp	R1	20.4	*Navicula sp.*	1.2	8.06	8.6	0.9	10.3	0.40	0.41	3.75	12.6(34.6%)	
				Cylindrotheca closterium										41.4(28.0%)
2005.04.12	Sp	dis	20.6	*Paralia sulcata*	0.2	8.01	6.9	1.9	62.4	7.32	0.56	3.33	41.5(44.2%)	82.9(36.1%)
2000.05.03	Sp	C1	21.1	*Ditylum brightwellii*	1.0	8.06	6.1	1.3	30.0	10.16	0.40	7.72	88.0(25.6%)	
				Plagiogramma vanheurckii										157.2(26.3%)
2000.10.31	A	dis	21.2	*Paralia sulcata*	0.2	8.25	6.6	1.6	27.0	10.34	0.22	6.07	22.8(34.4%)	45.6(25.2%)
2005.04.12	Sp	C1	21.2	*Paralia sulcata*	0.3	8.01	7.1	1.1	54.7	4.82	0.46	3.37	51.7(62.3%)	103.4(50.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2001.11.07	A	C1	21.3	*Thalassiosira rotula*	0.7	8.13	7.1	2.0	7.0	16.40	0.52	12.64	37.3(34.6%)	
				Chaetoceros debilis										51.6(19.6%)
2001.11.07	A	R1	21.3	*Thalassiosira rotula*	0.3	8.14	6.9	2.2	9.0	16.57	0.51	12.93	21.3(34.5%)	
				Chaetoceros debilis										34.8(19.1%)
2002.04.18	Sp	dis	21.4	*Coscinodiscus gigas*	0.1	7.89	7.1	2.2	70.0	18.92	0.93	5.61	81.1(16.4%)	
				Thalassiosira decipiens										302.0(27.2%)
2008.11.10	A	C2	21.5	*Karenia mikimotoi*	0.5	8.02	8.3	3.0	22.0	11.29	1.10	4.78	24.0(36.3%)	48.0(29.6%)
2004.04.13	Sp	dis	21.6	*Navicula sp.*	0.9	7.84	8.2	0.9	25.3	3.05	0.17	2.23	1.1(21.9%)	
				Cylindrotheca closterium										2.0(16.7%)
2003.07.15	Su	C2	22.0	*Paralia sulcata*	1.1	7.94	8.1	1.2	5.5	7.54	0.33	2.34	0.4(43.8%)	0.7(46.4%)
2008.11.10	A	R2	22.0	*Coscinodiscus sp.*	0.5	7.99	8.2	3.4	22.0	7.87	0.96	3.59	9.7(35.4%)	
				Chaetoceros debilis										42.0(28.0%)
2009.10.21	A	R1	22.0	*Coscinodiscus sp.*	0.7	7.86	6.5	1.0	18.4	13.75	0.76	18.28	9.7(37.5%)	
				Thalassiosira sp. 1										18.0(37.5%)
2003.07.15	Su	R2	22.2	*Prorocentrum micans*	1.0	7.87	8.0	1.5	6.5	6.29	0.29	2.88	2.2(46.2%)	
				Paralia sulcata										2.6(36.1%)
2006.11.16	A	dis	22.2	*Paralia sulcata*	0.1	8.07	7.2	0.7	107.6	9.68	0.38	7.81	11.5(35.1%)	23.0(23.0%)
2001.04.24	Sp	dis	22.3	*Prorocentrum micans*	0.3	7.78	7.6	2.3	36.0	2.96	0.15	4.74	85.2(26.5%)	
				Paralia sulcata										138.0(19.1%)
2008.11.10	A	ref	22.6	*Thalassiosira sp. 1*	0.5	8.05	7.3	2.1	24.0	6.16	0.81	3.41	29.9(34.8%)	77.0(41.6%)
2008.11.10	A	C1	23.0	*Coscinodiscus sp.*	0.3	7.99	7.8	2.0	23.0	12.85	1.04	4.91	19.3(31.7%)	
				Chaetoceros debilis										161.0(51.9%)
2008.11.10	A	R1	23.0	*Coscinodiscus sp.*	0.5	8.00	7.5	5.2	21.6	8.51	1.17	4.73	19.3(29.9%)	
				Rhizosolenia delicatula										42.0(29.2%)
2003.07.15	Su	In	23.2	*Paralia sulcata*	0.9	7.99	8.3	1.5	6.8	6.26	0.31	3.11	1.6(78.5%)	3.3(74.2%)
2008.11.10	A	L2	23.5	*Ceratium fusus*	0.5	8.04	7.3	4.0	24.9	9.50	0.92	2.97	13.8(25.5%)	
				Skeletonema costatum										48.0(22.2%)
2009.05.09	Sp	dis	23.6	*Alexandrium sp.*	0.4	8.22	7.0	3.2	22.9	4.30	0.42	5.84	41.4(83.6%)	
				Chroomonas sp.										143.0(57.0%)
2003.04.15	Sp	dis	23.8	*Paralia sulcata*	0.6	8.12	8.3	2.4	7.4	6.19	0.37	5.17	11.9(43.4%)	
				Cylindrotheca closterium										40.4(46.6%)
2003.07.15	Su	C1	23.8	*Paralia sulcata*	0.5	7.97	7.7	1.5	5.5	7.18	0.29	3.07	1.2(74.2%)	2.4(63.5%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2003.07.15	Su	L1	23.9	*Paralia sulcata*	0.7	7.97	8.1	1.3	5.1	7.49	0.36	2.80	1.8(40.1%)	3.6(38.2%)
2008.11.10	A	In	23.9	*Coscinodiscus sp.*	0.4	7.97	7.8	2.3	28.3	13.02	1.18	5.98	38.7(38.7%)	
				Paralia sulcata										65.0(38.9%)
2003.07.15	Su	R1	24.0	*Paralia sulcata*	1.0	7.94	7.9	1.6	7.4	7.04	0.23	3.20	2.9(68.2%)	5.8(65.9%)
2003.07.15	Su	ref	24.0	*Paralia sulcata*	1.0	7.95	8.4	1.8	8.2	6.65	0.35	2.15	1.4(59.1%)	2.9(67.6%)
2008.11.10	A	L1	24.0	*Ditylum brightwellii*	0.5	8.01	7.3	2.6	23.2	10.21	0.95	1.62	48.9(63.1%)	
				Chroomonas sp.										36.0(33.3%)
2003.10.21	A	dis	24.1	*Pseudonitschia pungens*	0.6	7.99	8.6	2.1	12.8	9.58	0.56	4.33	7.1(31.5%)	14.3(36.2%)
2007.11.05	A	dis	24.2	*Rhizosolenia alata form a gracillima*	0.4	8.17	5.8	2.8	25.3	10.38	0.23	3.32	26.3(77.5%)	54.0(81.8%)
2000.05.03	Sp	dis	24.7	*Coscinodiscus marginatus*	0.3	8.03	5.9	1.9	34.0	13.01	0.38	7.95	27.1(12.5%)	
				Asterionellopsis kariana										57.6(10.0%)
2008.05.13	Sp	dis	25.0	*Coscinodiscus sp.*	1.0	7.79	6.9	2.1	22.9	0.00	0.35	1.51	9.7(47.3%)	
				Chaetoceros pseudocrinitus										12.0(33.3%)
2005.11.01	A	dis	25.1	*Paralia sulcata*	0.1	8.09	7.2	1.7	40.6	14.07	0.61	3.69	15.5(74.8%)	31.0(79.5%)
2006.05.07	Sp	dis	25.3	*Navicula sp.*	0.8	8.01	8.3	1.6	8.0	1.20	0.49	3.76	30.8(49.8%)	57.2(25.7%)
2003.07.15	Su	L2	25.4	*Paralia sulcata*	0.8	7.94	8.3	0.9	9.9	9.07	0.18	2.71	2.4(71.0%)	4.8(65.6%)
2007.05.07	Sp	dis	25.4	*Ditylum brightwellii*	0.9	8.14	7.8	3.9	54.1	14.29	0.77	9.14	24.5(36.2%)	
				Chroomonas sp.										57.0(28.8%)
2002.07.23	Su	ref	25.7	*Eucampia zodiacus*	0.7	8.26	6.7	1.7	16.0	5.84	0.42	13.33	275.3(47.5%)	1,101.0(54.0%)
2004.07.22	Su	ref	25.7	*Ditylum brightwellii*	0.5	8.17	6.7	1.1	12.7	2.93	0.35	1.10	16.9(47.1%)	
				Pleurosigma sp.										25.0(44.4%)
2001.11.07	A	dis	25.8	*Thalassiosira rotula*	0.2	8.05	5.8	1.5	21.0	22.05	1.15	9.56	26.6(32.4%)	36.0(15.7%)
2004.07.22	Su	In	25.8	*Eucampia zodiacus*	0.5	8.13	6.3	1.9	8.7	3.48	0.50	1.35	2.6(21.3%)	10.5(33.3%)
2009.08.21	Su	R1	25.8	*Stephanopyxis palmeriana*	2.5	8.22	7.2	2.9	9.3	1.42	0.22	9.04	12.0(68.0%)	24.0(40.0%)
2002.07.23	Su	C2	25.9	*Eucampia zodiacus*	1.8	8.21	6.7	1.4	10.0	2.45	0.26	3.99	290.2(57.0%)	1160.9(55.2%)
2002.07.23	Su	In	25.9	*Eucampia zodiacus*	0.7	8.26	6.5	1.8	11.0	7.32	0.46	7.86	272.5(40.8%)	1090.0(45.4%)
2002.07.23	Su	L1	25.9	*Eucampia zodiacus*	0.7	8.30	7.7	1.7	10.0	2.84	0.15	10.80	262.9(51.2%)	1051.5(53.5%)
2009.08.21	Su	ref	25.9	*Chaetoceros sp.*	0.8	8.23	7.7	3.6	10.5	2.46	0.26	13.71	32.8(34.5%)	274.0(48.8%)
2009.08.21	Su	L2	26.1	*Chaetoceros sp.*	2.0	8.21	7.3	3.1	8.7	3.79	0.34	14.18	25.6(30.0%)	214.0(47.2%)
2002.07.23	Su	R2	26.2	*Eucampia zodiacus*	1.1	8.24	6.9	1.1	11.0	3.81	0.28	8.00	236.5(55.5%)	945.9(55.0%)
2009.08.21	Su	C2	26.2	*Chaetoceros sp. 1*	3.0	8.18	6.9	3.5	8.3	2.87	0.28	10.64	24.2(34.8%)	202.0(50.8%)
2009.08.21	Su	R2	26.2	*Chaetoceros sp. 1*	4.5	8.22	7.1	1.2	8.5	1.02	0.22	6.97	39.2(29.0%)	327.0(41.3%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2004.07.22	Su	L1	26.3	*Eucampia zodiacus*	1.0	8.17	6.7	1.6	8.7	5.47	0.45	0.96	25.8(37.5%)	103.2(60.2%)
2004.07.22	Su	C1	26.5	*Ditylum brightwellii*	0.3	8.09	6.1	1.3	11.7	2.27	0.29	0.70	49.5(62.7%)	
				Coscinodiscus sp. 1										6.1(14.3%)
2009.10.21	A	dis	26.5	*Paralia sulcata*	0.1	7.81	6.4	1.0	24.0	10.56	0.94	16.85	24.0(88.9%)	48.0(88.9%)
2005.08.02	Su	In	26.6	*Eucampia zodiacus*	0.6	8.11	6.8	1.1	6.2	7.42	0.37	1.72	21.8(20.1%)	
				Leptocylindrus danicus										106.0(28.3%)
2009.08.21	Su	In	26.6	*Chaetoceros sp.*	2.0	8.20	7.3	1.1	10.2	4.12	0.37	4.99	30.0(25.4%)	250.0(44.6%)
2009.08.21	Su	L1	26.6	*Chaetoceros sp.*	2.0	8.17	7.5	4.3	10.2	2.59	0.37	10.29	18.6(23.8%)	155.0(33.8%)
2002.07.23	Su	L2	26.7	*Eucampia zodiacus*	1.1	8.05	8.0	1.8	11.0	4.46	0.05	4.68	253.0(52.3%)	1011.9(52.7%)
2004.07.22	Su	L2	26.7	*Protoperidinium leonis*	1.5	8.15	6.4	2.1	6.5	2.76	0.41	0.54	4.6(18.8%)	
				Eucampia zodiacus										14.8(33.3%)
2004.07.22	Su	R1	26.7	*Protoperidinium sp.*	1.5	8.12	6.6	1.6	11.0	4.94	0.43	0.90	4.6(35.7%)	
				Paralia sulcata										6.3(20.0%)
2004.07.22	Su	R2	26.7	*Protoperidinium pellucidum*	0.5	8.11	6.3	1.6	5.8	3.50	0.51	0.75	4.4(32.9%)	
				Chaetoceros debilis										10.2(38.5%)
2005.08.02	Su	L1	26.7	*Eucampia zodiacus*	0.9	8.11	7.1	1.1	12.3	9.84	0.33	3.11	12.0(19.4%)	48.0(19.4%)
2005.08.02	Su	ref	26.9	*Eucampia zodiacus*	0.8	8.09	8.0	1.1	9.9	2.13	0.31	1.32	59.8(39.1%)	239.0(47.5%)
2007.08.07	Su	ref	27.1	*Stephanopyxis turris*	2.0	8.06	6.1	8.1	9.4	10.93	0.46	4.12	61.3(41.1%)	
				Paralia sulcata										54.0(16.4%)
2002.07.23	Su	R1	27.2	*Eucampia zodiacus*	1.0	8.21	6.2	1.9	11.0	3.56	0.44	4.44	234.0(56.5%)	935.9(56.1%)
2005.08.02	Su	C1	27.3	*Paralia sulcata*	1.0	8.12	7.0	1.5	9.6	5.97	0.42	1.15	15.5(13.6%)	
				Eucampia zodiacus										62.0(16.9%)
2007.08.07	Su	L2	27.5	*Stephanopyxis turris*	2.0	8.08	6.3	5.4	12.3	3.59	0.25	0.62	70.1(54.6%)	48.0(27.6%)
2004.07.22	Su	C2	27.6	*Protoperidinium pellucidum*	1.0	8.16	6.9	1.3	8.8	2.78	0.56	0.47	13.2(40.7%)	
				Eucampia zodiacus										14.1(25.0%)
2005.08.02	Su	C2	27.6	*Guinardia striata*	1.3	8.12	7.4	1.4	5.9	4.00	0.39	1.84	20.5(25.3%)	
				Eucampia zodiacus										69.0(32.2%)
2007.08.07	Su	C2	27.8	*Stephanopyxis turris*	2.0	8.01	6.1	5.4	14.1	4.50	0.25	0.27	100.7(73.2%)	69.0(29.5%)
2008.08.12	Su	C2	28.0	*Eucampia groenlandica*	2.0	7.70	4.8	5.6	18.2	0.00	0.17	2.71	104.0(71.2%)	208.0(62.5%)
2007.08.07	Su	In	28.1	*Stephanopyxis turris*	2.0	8.00	6.0	1.3	11.9	6.05	0.28	3.86	35.0(42.2%)	
				Chaetoceros curvisetus										185.0(49.9%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2007.08.07	Su	R2	28.2	*Stephanopyxis turris*	1.8	7.98	6.7	3.2	13.2	6.96	0.36	0.18	43.8(50.4%)	
				Leptocylindrus danicus										42.0(28.0%)
2008.08.12	Su	ref	28.2	*Stephanopyxis turris*	2.0	7.73	5.2	5.7	20.1		0.15	2.19	156.2(59.7%)	107.0(21.6%)
2000.08.01	Su	C2	28.6	*Stephanopyxis turris*	1.2	8.01	7.1	1.3	2.0	11.35	0.24	5.31	75.3(45.5%)	
				Chaetoceros compressus										54.0(13.9%)
2005.08.02	Su	R1	28.6	*Eucampia zodiacus*	0.9	8.11	6.8	1.2	5.7	3.62	0.35	1.08	20.0(34.6%)	80.0(51.3%)
2007.08.07	Su	C1	28.6	*Stephanopyxis turris*	2.0	7.99	6.2	7.2	13.6	4.62	0.23	1.48	74.5(85.7%)	51.0(41.5%)
2007.08.07	Su	L1	28.6	*Stephanopyxis turris*	2.0	8.09	5.9	3.6	10.8	5.83	0.29	1.48	35.0(39.0%)	
				Chaetoceros curvisetus										214.0(52.1%)
2000.08.01	Su	In	28.8	*Stephanopyxis turris*	0.8	8.03	6.2	1.8	7.0	11.13	0.23	5.60	82.3(39.2%)	56.4(12.7%)
2000.08.01	Su	ref	28.8	*Ditylum brightwellii*	0.7	7.91	6.6	1.1	11.0	10.56	0.26	6.18	127.1(38.1%)	
				Chaetoceros compressus										92.4(21.8%)
2008.08.12	Su	C1	28.8	*Eucampia groenlandica*	1.5	7.72	5.4	6.1	20.0		0.17	1.86	12.0(52.1%)	
				Chroomonas sp.										179.0(74.9%)
2001.08.07	Su	ref	28.9	*Stephanopyxis turris*	0.9	8.05	6.3	1.0	21.0	5.44	0.43	7.82	82.3(40.4%)	
				Thalassiothrix frauenfeldii										72.0(18.2%)
2000.08.01	Su	C1	29.0	*Stephanopyxis turris*	1.0	7.84	6.5	1.5	5.0	11.56	0.22	6.08	101.6(41.9%)	69.6(19.1%)
2008.08.12	Su	L2	29.0	*Stephanopyxis turris*	2.5	7.68	5.1	4.8	20.2		0.17	3.61	43.8(33.8%)	
				Eucampia groenlandica										54.0(20.0%)
2008.08.12	Su	R2	29.0	*Eucampia groenlandica*	2.0	7.84	6.2	3.9	20.6		0.11	2.17	86.5(36.8%)	173.0(37.6%)
2000.08.01	Su	L1	29.1	*Stephanopyxis turris*	1.0	7.78	6.7	1.5	11.0	10.92	0.28	5.38	145.4(58.5%)	99.6(21.6%)
2007.08.07	Su	R1	29.3	*Chaetoceros compressus*	1.8	7.98	6.2	3.3	17.6	13.45	0.60	0.63	8.6(32.2%)	
				Chroomonas sp.										155.0(42.5%)
2009.08.21	Su	C1	29.4	*Chaetoceros sp.*	1.8	8.19	7.4	2.0	9.3	1.75	0.32	7.75	20.0(20.5%)	167.0(37.3%)
2000.08.01	Su	L2	29.5	*Stephanopyxis turris*	0.8	7.98	7.4	1.4	9.0	10.19	0.25	5.94	143.7(49.2%)	
				Chaetoceros curvisetus										114.0(21.4%)
2000.08.01	Su	R2	29.5	*Stephanopyxis turris*	1.2	7.78	6.3	1.2	24.0	10.38	0.22	5.71	109.8(50.1%)	75.2(18.7%)
2001.08.07	Su	C2	29.6	*Stephanopyxis turris*	1.3	7.99	5.5	1.6	22.0	8.66	0.01	5.66	80.6(30.5%)	
				Thalassiothrix frauenfeldii										91.2(20.5%)
2001.08.07	Su	In	29.6	*Stephanopyxis turris*	0.9	8.02	6.1	1.5	22.0	10.36	0.05	14.48	140.2(49.2%)	96.0(18.7%)
2001.08.07	Su	C1	29.9	*Stephanopyxis turris*	1.0	8.06	6.0	2.0	23.0	7.93	0.03	6.97	101.6(37.2%)	
				Leptocylindrus danicus										84.0(17.1%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2004.07.22	Su	dis	30.0	*Protoperidinium pellucidum*	0.2	8.05	6.6	2.3	13.5	4.12	0.40	0.69	4.4(74.5%)	
				Ephemera planamembranacea										2.0(25.0%)
2001.08.07	Su	L2	30.1	*Stephanopyxis turris*	1.0	7.92	7.8	1.7	19.0	7.87	0.68	5.46	117.4(34.3%)	
				Leptocylindrus danicus										81.6(17.3%)
2006.08.17	Su	In	30.1	*Detonula pumila*	1.0	7.99	5.2	1.1	11.3	12.44	0.51	6.88	19.0(31.3%)	38.0(19.4%)
2001.08.07	Su	L1	30.2	*Stephanopyxis turris*	1.0	8.10	6.1	2.3	21.0	8.11	0.00	6.93	64.8(35.9%)	
				Thalassiothrix frauenfeldii										78.0(20.2%)
2001.08.07	Su	R2	30.2	*Stephanopyxis turris*	1.9	8.09	6.0	2.0	20.0	9.91	0.46	6.36	59.6(31.5%)	
				Thalassiothrix frauenfeldii										67.2(19.0%)
1999.08.17	Su	In	30.3	*Stephanopyxis turris*	0.9	8.07	8.3	1.9	23.0	8.81	0.23	5.10	151.8(44.4%)	
				Eucampia zodiacus										152.4(23.9%)
2003.07.15	Su	dis	30.3	*Paralia sulcata*	0.3	7.92	8.2	1.7	11.9	7.30	0.27	3.60	1.4(67.2%)	2.8(61.3%)
2000.08.01	Su	R1	30.4	*Stephanopyxis turris*	1.5	7.76	6.4	1.8	5.0	9.42	0.20	6.17	73.6(36.7%)	
				Chaetoceros compressus										61.2(16.5%)
2008.08.12	Su	In	30.5	*Stephanopyxis turris*	2.0	7.77	5.8	6.6	23.7		0.25	4.16	35.0(44.4%)	
				Chaetoceros sp.										60.0(28.6%)
2008.08.12	Su	L1	30.5	*Stephanopyxis turris*	2.0	7.68	5.1	4.5	20.3		0.11	2.26	87.6(44.8%)	
				Eucampia groenlandica										125.0(32.6%)
1999.08.17	Su	R2	30.7	*Stephanopyxis turris*	1.0	8.11	8.3	1.6	22.0	9.10	0.33	4.55	282.1(59.7%)	
				Eucampia zodiacus										273.6(32.8%)
1999.08.17	Su	ref	30.7	*Stephanopyxis turris*	1.0	8.16	8.6	1.5	22.0	7.67	0.28	4.05	199.7(40.2%)	
				Eucampia zodiacus										213.6(29.8%)
2006.08.17	Su	L1	30.7	*Detonula pumila*	1.0	8.04	6.2	1.1	6.7	7.28	0.61	6.73	36.5(40.0%)	
				Eucampia zodiacus										73.0(24.5%)
1999.08.17	Su	R1	30.9	*Stephanopyxis turris*	1.0	8.03	8.0	1.8	23.0	9.01	0.24	5.09	296.1(46.4%)	
				Eucampia zodiacus										452.4(38.6%)
2002.07.23	Su	C1	30.9	*Eucampia zodiacus*	0.7	8.18	7.1	1.9	11.0	1.73	0.24	10.29	235.7(58.8%)	942.9(57.7%)
2008.11.10	A	dis	31.0	*Coscinodiscus sp.*	0.2	7.91	7.3	1.9	25.1	11.17	0.89	4.97	29.0(76.7%)	
				Skeletonema costatum										30.0(41.7%)
2001.08.07	Su	R1	31.1	*Stephanopyxis turris*	1.5	8.09	5.8	1.2	19.0	9.52	0.03	8.42	126.1(58.2%)	86.4(20.8%)
2006.08.17	Su	C1	31.1	*Detonula pumila*	0.9	7.99	5.2	1.2	9.2	9.28	0.43	6.84	15.0(33.3%)	30.0(19.7%)
2006.08.17	Su	ref	31.1	*Detonula pumila*	0.9	7.99	5.9	0.7	11.6	7.99	0.75	8.74	27.5(27.2%)	55.0(17.4%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2006.08.17	Su	R1	31.2	*Detonula pumila*	1.0	8.00	5.7	1.0	7.8	11.06	1.00	6.37	32.0(41.8%)	64.0(21.7%)
2007.08.07	Su	dis	31.4	*Stephanopyxis turris*	1.8	7.95	5.4	7.5	16.7	8.66	0.38	3.98	35.0(31.7%)	
				Chaetoceros curvisetus										95.0(33.8%)
2008.08.12	Su	R1	31.5	*Stephanopyxis turris*	3.0	7.77	5.7	3.8	16.4		0.19	2.14	17.5(25.0%)	
				Chroomonas sp.										226.0(64.2%)
1999.08.17	Su	C2	31.8	*Stephanopyxis turris*	1.5	8.07	8.1	1.8	22.0	8.89	0.24	4.74	226.0(57.6%)	154.8(24.2%)
1999.08.17	Su	L2	31.8	*Stephanopyxis turris*	1.0	8.05	7.9	1.8	22.0	7.18	0.27	4.95	208.5(51.6%)	
				Eucampia zodiacus										216.0(28.9%)
1999.08.17	Su	L1	32.0	*Stephanopyxis turris*	1.0	8.14	8.2	1.6	22.0	7.89	0.31	4.17	304.8(66.7%)	
				Eucampia zodiacus										224.4(26.0%)
2002.07.23	Su	dis	32.8	*Eucampia zodiacus*	0.6	8.17	6.8	1.8	15.0	5.48	0.44	7.69	220.4(51.0%)	881.7(52.1%)
2005.08.02	Su	dis	33.7	*Eucampia zodiacus*	0.4	8.07	6.6	2.2	16.6	5.05	0.29	1.94	22.0(38.8%)	88.0(50.0%)
1999.08.17	Su	C1	34.2	*Stephanopyxis turris*	1.0	8.11	8.6	1.9	24.0	8.71	0.34	4.60	290.8(67.5%)	199.2(31.2%)
2006.08.17	Su	C2	34.3	*Detonula pumila*	1.2	7.95	5.4	1.2	4.8	17.24	0.55	6.57	15.0(31.0%)	
				Chaetoceros sp.										72.0(30.8%)
2009.08.21	Su	dis	34.4	*Chaetoceros sp.*	1.8	8.14	7.1	2.9	10.0	3.11	0.26	13.05	36.3(19.7%)	303.0(42.7%)
1999.08.17	Su	dis	35.1	*Stephanopyxis turris*	0.4	8.12	7.7	2.0	27.0	9.44	0.30	5.29	113.9(36.4%)	
				Eucampia zodiacus										208.8(28.5%)
2001.08.07	Su	dis	35.2	*Stephanopyxis turris*	0.8	7.98	5.5	1.5	21.0	9.00	1.55	7.83	133.2(47.5%)	91.2(20.4%)
2000.08.01	Su	dis	35.5	*Stephanopyxis turris*	0.5	7.81	5.8	1.9	13.0	9.77	0.21	5.66	106.9(39.6%)	73.2(18.0%)
2008.08.12	Su	dis	36.2	*Eucampia groenlandica*	1.5	7.70	5.5	4.9	22.5		0.38	6.15	50.5(79.0%)	101.0(56.4%)
2006.08.17	Su	dis	37.6	*Detonula pumila*	0.9	7.94	5.4	1.1	8.0	2.53	0.52	7.20	19.5(43.8%)	39.0(22.5%)
1999.11.09	A	C1		*Paralia sulcata*	0.5			2.5	22.0	9.62	0.36	5.34	48.7(38.7%)	97.4(32.7%)
1999.11.09	A	C2		*Paralia sulcata*	1.0			1.7	19.0	10.15	0.25	5.41	57.9(37.1%)	115.8(34.1%)
1999.11.09	A	dis		*Ceratium tripos*	0.1			1.7	43.0	10.08	0.33	5.30	106.1(47.4%)	76.4(25.0%)
1999.11.09	A	In		*Paralia sulcata*	0.4			2.2	26.0	9.07	0.28	5.70	67.3(46.2%)	134.6(37.8%)
1999.11.09	A	L1		*Paralia sulcata*	0.8			1.9	22.0	10.35	0.31	5.66	26.4(23.5%)	52.8(22.8%)
1999.11.09	A	L2		*Paralias ulcata*	0.7			2.1	21.0	8.82	0.32	5.78	37.9(27.4%)	75.8(24.7%)
1999.11.09	A	R1		*Ditylum brightwellii*	0.2			1.7	43.0	10.01	0.26	5.18	39.1(26.9%)	
				Paralia sulcata										49.8(20.2%)
1999.11.09	A	R2		*Paralia sulcata*	0.7			1.8	21.0	9.88	0.28	5.24	44.4(27.3%)	88.8(25.9%)
1999.11.09	A	ref		*Ceratium tripos*	0.7			1.6	21.0	9.50	0.31	5.12	79.6(31.4%)	
				Paralia sulcata										99.6(30.5%)

Table A-2. The maximum biomass(MB) and abundance(MA) of the top dominant species in Hanul NPP from 1999 to 2009

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2001.02.13	W	L2	7.8	*Paralia sulcata*	12.0	8.11	8.1	1.27	23.0	12.09	1.10	6.11	8.4(31.7%)	16.8(25.5%)
2000.02.22	W	L2	8.5	*Odontella sinensis*	0.0	8.01	6.8	1.29	10.0	7.85	0.20	5.42	4.2(11.6%)	32.4(23.1%)
2000.02.22	W	C2	8.8	*Ditylum brightwellii*	0.0	8.05	6.1	1.03	8.0	8.48	0.28	5.33	19.6(37.1%)	14.4(15.0%)
2001.02.13	W	L1	8.9	*Odontella sinensis*	12.0	8.03	8.6	1.38	22.0	12.37	1.18	5.02	4.2(14.8%)	16.8(24.1%)
2000.02.22	W	C1	9.1	*Stephanopyxis turris*	0.0	8.06	5.8	1.33	11.0	8.92	0.32	5.25	5.3(13.9%)	9.6(10.5%)
2000.02.22	W	L1	9.3	*Ceratium furca*	15.0	7.93	6.8	1.31	10.0	8.97	0.27	5.88	4.5(21.5%)	26.4(28.9%)
2000.02.22	W	ref	9.3	*Ditylum brightwellii*	8.0	8.14	6.1	1.28	9.0	7.36	0.34	5.09	58.7(54.6%)	19.2(18.0%)
2001.02.13	W	In	9.5	*Ditylum brightwellii*	5.0	8.04	7.5	1.26	24.0	12.26	0.85	6.90	19.6(44.5%)	7.2(14.0%)
2006.02.15	W	C2	9.5	*Gymnodinium sp.*	17.0	7.40	11.0	1.42	4.9	7.27	0.91	4.12	0.3(50.2%)	0.6(40.0%)
2000.02.22	W	In	9.6	*Ditylum brightwellii*	8.0	8.15	6.2	1.37	12.0	9.34	0.32	5.53	9.8(24.2%)	13.2(11.8%)
2006.02.15	W	In	9.7	*Ditylum brightwellii*	6.0	7.37	11.0	1.23	5.7	7.48	0.65	3.59	1.5(34.6%)	1.8(32.8%)
2006.02.15	W	ref	9.9	*Navicula sp.*	12.0	7.54	10.6	1.53	4.5	6.86	0.76	3.45	0.4(26.5%)	0.7(19.4%)
2006.02.15	W	L1	10.0	*Navicula sp.*	12.0	7.44	10.7	1.26	7.7	9.06	0.84	4.81	0.2(15.9%)	0.3(12.5%)
2009.02.02	W	L1	10.0	*Gymnodinium sp.*	10.0	8.22	8.6	1.99	4.9	13.17	0.52	8.42	1.0(46.6%)	2.0(28.6%)
2002.02.05	W	L2	10.1	*Prorocentrum micans*	15.5	7.83	9.1	1.21	12.0	12.20	0.87	3.93	9.7(33.0%)	33.9(33.3%)
2002.04.18	Sp	In	10.1	*protoperidinium claudicans*	12.0	7.97	7.3	1.58	13.0	13.34	1.18	7.08	77.2(63.7%)	77.2(35.0%)
2002.02.05	W	In	10.3	*Eucampia zodiacus*	7.0	7.89	9.0	1.38	12.0	11.46	0.52	3.62	5.9(53.8%)	28.2(31.6%)
2005.04.19	Sp	dis	10.3	*Chaetoceros debilis*	8.0	8.24	9.6	1.23	4.8	4.33	0.26	2.41	21.0(21.2%)	175.5(35.8%)
2009.02.02	W	L2	10.3	*Gyrodinium spirale*	13.5	8.37	8.6	1.63	5.8	12.82	0.48	7.92	0.5(33.3%)	1.0(33.3%)
2009.02.02	W	ref	10.3	*Thalassiosira curviseriata*	14.0	8.32	8.2	2.11	7.6	13.17	0.48	7.57	0.8(29.2%)	2.0(22.2%)
2001.02.13	W	C1	10.4	*Coscinodiscus gigas*	12.0	8.13	9.4	1.09	26.0	11.52	0.70	7.87	5.8(21.9%)	7.2(14.3%)
2002.02.05	W	C2	10.4	*Protoperidinium brochii*	13.5	7.86	8.9	1.29	10.0	12.06	0.81	4.40	10.6(29.1%)	24.4(31.2%)
2001.02.13	W	R2	10.5	*Paralia sulcata*	13.0	8.07	8.1	1.45	21.0	11.89	0.69	8.09	5.4(35.4%)	10.8(28.1%)
2001.02.13	W	ref	10.5	*Ditylum brightwellii*	11.0	8.13	8.2	1.14	22.0	12.35	0.51	7.60	58.7(70.8%)	13.2(22.0%)
2002.02.05	W	L1	10.5	*Prorocentrum micans*	12.5	7.84	8.5	1.44	13.0	9.57	1.05	5.21	8.8(21.0%)	26.3(18.8%)
2006.05.07	Sp	C1	10.5	*Leptocylindrus danicus*	7.0	8.18	10.2	1.32	9.6	0.33	0.07	1.49	2.1(35.5%)	18.9(46.4%)
2009.02.02	W	In	10.5	*Scrippsiella trochoidea*	10.0	8.37	8.2	1.51	6.4	13.89	0.55	8.28	0.7(36.9%)	1.0(14.3%)
2002.02.05	W	ref	10.6	*Thalassiosira rotula*	10.0	7.89	8.7	1.55	13.0	7.37	0.56	4.28	6.4(26.6%)	13.0(17.6%)
2006.02.15	W	R1	10.6	*Navicula sp.*	12.0	7.51	9.9	0.99	5.2	8.24	0.74	4.68	0.6(41.2%)	1.1(34.5%)
2001.02.13	W	R1	10.7	*Paralia sulcata*	13.0	8.14	8.1	1.61	20.0	12.35	0.84	9.77	6.6(39.3%)	13.2(36.7%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2002.02.05	W	C1	10.7	*Eucampia zodiacus*	13.0	7.88	8.8	0.84	10.0	12.24	0.06	6.68	6.0(43.2%)	24.2(36.4%)
2004.02.04	W	In	10.7	*Thalassiosira sp.*	6.0	8.14	8.6	1.12	10.5	12.65	0.44	0.96	42.0(42.0%)	302.3(51.8%)
2002.02.05	W	R2	10.8	*Plagiogramma vanheurckii*	12.5	7.87	8.7	0.88	11.0	10.66	0.72	6.53	22.7(52.7%)	45.3(50.0%)
2002.04.18	Sp	L2	10.8	*Chaetoceros distans*	12.5	8.03	7.7	0.68	9.0	12.42	0.57	6.73	22.1(42.6%)	184.8(48.3%)
2004.02.04	W	L1	10.8	*Thalassiosira sp.*	12.0	8.12	9.7	1.37	4.9	7.93	0.50	1.39	24.1(44.4%)	244.6(61.0%)
2002.04.18	Sp	C2	10.9	*Chaetoceros distans*	14.0	7.84	7.3	1.08	11.0	12.92	0.62	5.23	19.8(50.0%)	165.0(58.6%)
2005.04.19	Sp	In	10.9	*Thalassiosira rotula*	8.0	8.25	7.4	1.16	10.6	3.27	0.22	2.15	30.0(23.6%)	298.1(34.3%)
2009.02.02	W	C2	10.9	*Gyrodinium spirale*	13.5	8.35	8.4	1.99	7.2	12.82	0.52	8.28	0.5(48.7%)	1.0(33.3%)
2002.04.18	Sp	L1	11.0	*Prorocentrum micans*	14.8	8.02	7.9	1.43	10.0	13.44	0.36	4.08	12.2(22.7%)	73.3(42.9%)
2005.04.19	Sp	L1	11.0	*Chaetoceros debilis*	9.0	8.29	11.7	1.23	4.5	3.13	0.21	2.02	24.4(19.1%)	203.6(33.9%)
1999.02.09	W	In	11.1	*Ceratium furca*	7.0	8.07	9.1	0.52	8.0	4.68	0.69	5.67	6.0(16.8%)	19.2(25.4%)
1999.02.09	W	L1	11.1	*Paralia sulcata*	10.0	8.06	9.2	0.90	7.0	4.52	0.65	4.78	11.4(27.5%)	22.8(29.2%)
2006.05.07	Sp	C2	11.1	*Chaetoceros densus*	7.5	8.10	9.1	1.45	6.1	0.27	0.05	1.14	2.6(33.6%)	22.1(48.0%)
1999.02.09	W	L2	11.2	*Paralia sulcata*	12.0	8.07	9.0	1.26	7.0	4.51	0.82	5.83	10.8(32.6%)	21.6(34.0%)
2004.02.04	W	ref	11.2	*Pseudo-nitzchia spp.*	13.0	8.15	8.8	1.15	6.1	11.46	0.30	1.49	1.8(17.6%)	13.0(24.6%)
2006.02.15	W	C1	11.2	*Protoperidinium minisculum*	15.0	7.38	10.4	1.75	4.8	7.51	1.10	3.16	0.4(28.2%)	0.5(16.7%)
1999.02.09	W	C1	11.3	*Ditylum brightwellii*	13.0	8.08	8.9	1.03	5.0	4.46	0.73	5.34	39.1(50.6%)	26.4(34.9%)
2002.04.18	Sp	ref	11.3	*Licmophora abbreviata*	14.5	7.93	7.2	1.89	18.0	13.82	0.37	6.49	8.5(19.5%)	43.8(28.6%)
2004.02.04	W	L2	11.3	*Thalassiosira sp.*	13.0	8.13	8.6	1.13	3.5	10.67	0.45	1.46	6.4(27.5%)	67.7(44.9%)
2005.02.15	W	ref	11.3	*Prorocentrum sp.*	16.0	8.29	9.3	0.84	4.5	6.90	0.27	3.41	1.1(36.3%)	7.9(47.9%)
2003.01.21	W	In	11.4	*Paralia sulcata*	3.5	8.18	8.8	1.32	4.7	11.60	1.53	6.43	6.4(26.5%)	54.6(46.0%)
2003.01.21	W	L1	11.4	*Gymnodinium sp.*	15.0	8.06	9.4	1.44	5.1	11.35	0.53	2.88	1.2(12.4%)	14.3(28.4%)
2004.02.04	W	C2	11.4	*Ditylum brightwellii*	14.0	8.15	8.1	1.43	9.9	10.50	0.46	1.47	4.2(44.1%)	9.4(31.0%)
2003.01.21	W	L2	11.5	*Gymnodinium sp.*	15.0	8.17	9.3	1.29	3.2	11.10	1.45	2.84	2.3(24.3%)	10.5(23.1%)
2005.02.15	W	In	11.5	*Gymnodinium sp.*	6.0	8.28	9.2	0.59	2.4	6.74	0.27	5.05	0.8(21.0%)	5.9(36.9%)
2005.04.19	Sp	ref	11.5	*Chaetoceros debilis*	9.0	8.30	13.0	1.19	3.8	2.84	0.16	2.85	31.1(22.2%)	259.9(29.2%)
1999.02.09	W	C2	11.6	*Guinardia flaccida*	13.0	8.11	9.3	0.94	6.0	7.24	0.72	4.26	12.3(24.4%)	14.4(22.2%)
2000.02.22	W	R2	11.6	*Ditylum brightwellii*	0.0	8.08	6.0	1.24	8.0	8.20	0.28	5.47	19.6(32.7%)	21.6(22.2%)
2005.02.15	W	R1	11.7	*Prorocentrum sp.*	14.0	8.28	9.7	0.98	2.7	5.21	0.36	5.80	1.4(35.6%)	10.6(54.0%)
1999.02.09	W	ref	11.8	*Coscinodiscus centrialis*	13.0	8.06	8.9	0.77	6.0	3.42	0.66	4.74	5.8(20.6%)	16.8(26.4%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2000.02.22	W	R1	11.8	*Guinardia flaccida*	13.0	8.18	6.3	1.21	11.0	10.17	0.29	5.46	18.4(45.0%)	18.0(20.5%)
2009.02.02	W	C1	11.8	*Gymnodinium sp.*	11.0	8.34	8.0	1.51	11.1	13.53	0.55	8.28	0.5(54.5%)	1.0(33.3%)
2005.04.19	Sp	C1	11.9	*Pseudo-nitzchia seriata*	9.0	8.29	13.0	1.23	6.6	3.62	0.37	3.19	32.1(21.7%)	230.6(29.2%)
2006.05.07	Sp	ref	11.9	*Chaetoceros densus*	8.5	8.14	10.0	1.03	8.0	0.49	0.14	1.48	2.4(29.7%)	19.9(56.8%)
2003.01.21	W	ref	12.0	*Paralia sulcata*	14.0	8.14	9.2	1.86	3.3	12.08	0.78	3.60	3.2(26.1%)	16.3(25.8%)
2006.05.07	Sp	L1	12.0	*Leptocylindrus danicus*	7.0	8.02	9.7	1.35	11.4	0.37	0.05	1.68	9.1(34.5%)	82.6(53.1%)
2005.02.15	W	C2	12.1	*Gymnodinium sp.*	18.0	8.26	9.6	0.69	4.1	6.57	0.32	5.95	1.5(30.1%)	6.5(38.7%)
2005.04.19	Sp	C2	12.1	*Pseudo-nitzchia seriata*	9.0	8.34	8.8	1.34	6.9	2.61	0.31	2.57	30.9(22.2%)	412.9(41.4%)
2006.05.07	Sp	R1	12.2	*Chaetoceros densus*	7.0	8.14	9.9	1.08	10.3	0.48	0.09	1.73	2.8(31.7%)	23.2(39.3%)
2002.04.18	Sp	C1	12.3	*Prorocentrum micans*	14.0	7.85	7.8	1.49	13.0	13.82	0.72	3.11	11.0(24.8%)	33.0(21.4%)
2004.02.04	W	R2	12.3	*Thalassiosira sp.*	7.0	8.13	9.1	1.14	9.4	9.50	0.34	1.41	19.7(28.6%)	288.9(59.9%)
2004.02.04	W	C1	12.5	*Thalassiosira sp.*	12.0	8.13	7.5	0.97	6.6	11.16	0.51	0.86	30.8(53.9%)	279.7(62.4%)
2004.02.04	W	R1	12.5	*Thalassiosira sp.*	6.0	8.13	9.2	1.38	7.6	10.74	0.44	1.32	22.7(28.0%)	289.2(59.3%)
2008.01.29	W	ref	12.5	*Gymnodinium sp.*	14.0	8.04	9.0	0.88	2.5	6.02	0.26	3.36	0.5(56.3%)	1.0(50.0%)
2002.02.05	W	R1	12.6	*Gymnodinium sp.*	12.5	7.88	8.5	1.36	11.0	11.89	0.36	5.43	4.8(21.4%)	24.2(29.4%)
2006.05.07	Sp	dis	12.6	*Leptocylindrus danicus*	6.0	8.18	9.8	0.87	6.0	0.86	0.22	1.52	1.6(26.8%)	15.0(37.0%)
2007.05.03	Sp	L1	12.6	*Chaetoceros decipiens*	8.0	8.23	8.0	0.91	7.2	1.14	0.03	0.86	7.1(51.6%)	39.0(54.2%)
2008.01.29	W	In	12.6	*Gymnodinium sp.*	9.0	8.06	8.7	0.67	19.8	14.53	0.42	3.71	0.5(43.2%)	1.0(33.3%)
2009.02.02	W	R2	12.7	*Gymnodinium sp.*	11.0	8.30	8.2	1.51	4.3	13.17	0.45	7.78	0.5(36.0%)	1.0(33.3%)
2000.04.25	Sp	L2	12.8	*Gonyaulax spinifera*	9.0	7.96	7.1	1.26	10.0	4.97	0.21	5.14	25.9(16.8%)	144.0(31.7%)
2003.01.21	W	C1	12.8	*Gymnodinium sp.*	15.0	8.16	8.9	1.49	1.7	12.33	0.77	3.61	3.7(33.1%)	12.3(28.7%)
2007.05.03	Sp	C2	12.8	*Chaetoceros decipiens*	13.0	8.29	7.9	0.95	7.4	1.21	0.06	0.64	2.4(32.7%)	13.0(39.4%)
2007.05.03	Sp	In	12.8	*Chaetoceros decipiens*	7.5	8.33	7.9	0.91	9.2	0.85	0.10	0.71	5.3(31.0%)	29.0(38.2%)
2008.01.29	W	C2	12.8	*Gymnodinium sp.*	14.0	8.07	8.5	0.80	16.1	8.12	0.26	11.64	0.5(100.0%)	1.0(100.0%)
2007.05.03	Sp	ref	12.9	*Chaetoceros decipiens*	13.0	8.28	7.9	1.16	10.7	0.71	0.16	0.50	5.1(42.4%)	28.0(45.9%)
2000.04.25	Sp	L1	13.1	*Gonyaulax spinifera*	7.5	7.98	7.7	1.22	11.0	5.35	0.21	4.60	46.3(30.0%)	121.2(30.7%)
2003.04.22	Sp	In	13.2	*Leptocylindrus danicus*	5.0	8.11	8.0	1.35	6.4	1.13	0.26	1.51	119.0(67.9%)	1081.6(76.3%)
2003.04.22	Sp	L1	13.2	*Leptocylindrus danicus*	8.0	8.15	7.8	1.24	6.6	1.26	0.29	1.43	76.0(49.6%)	690.8(68.0%)
2007.02.06	W	C2	13.2	*Thalassiosira sp.*	14.0	8.16	8.7	1.00	15.1	8.55	0.23	2.00	4.7(40.3%)	12.0(42.9%)
2007.05.03	Sp	C1	13.2	*Chaetoceros decipiens*	11.0	8.29	7.9	0.89	9.4	1.00	0.06	0.79	6.6(57.3%)	36.0(55.4%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2003.04.22	Sp	C2	13.3	*Leptocylindrus danicus*	14.0	8.08	8.2	1.53	11.9	1.68	0.18	1.45	21.2(44.1%)	193.2(49.7%)
2004.04.28	Sp	L1	13.3	*Cerataulina pelagica*	1.8	8.25	8.3	1.27	4.6	3.30	0.23	0.74	94.3(69.0%)	162.5(77.1%)
2000.02.22	W	dis	13.4	*Guinardia flaccida*	5.0	8.12	6.2	1.56	14.0	8.56	0.33	6.02	3.1(11.1%)	19.2(18.6%)
2003.04.22	Sp	ref	13.4	*Leptocylindrus danicus*	14.0	8.13	8.2	1.67	6.3	1.32	0.24	1.43	30.5(48.8%)	277.4(49.6%)
2003.07.22	Su	ref	13.4	*Gymnodinium sp.*	14.0	8.13	8.2	1.21	4.8	3.33	0.26	3.43	17.5(57.5%)	35.1(33.7%)
2008.01.29	W	C1	13.4	*Thalassiosira sp.*	12.5	8.05	8.8	0.86	12.4	3.35	0.36	2.43	0.4(100.0%)	1.0(100.0%)
2000.04.25	Sp	C2	13.5	*protoperidinium claudicans*	10.0	8.00	6.9	0.98	12.0	6.00	0.17	4.81	33.6(18.5%)	148.8(28.9%)
2000.04.25	Sp	In	13.5	*Gonyaulax spinifera*	8.0	8.07	7.3	1.13	11.0	7.01	0.22	5.11	39.5(20.2%)	189.6(32.7%)
2000.04.25	Sp	ref	13.5	*Ceratium tripos*	8.0	7.94	7.0	1.04	9.0	5.36	0.29	6.01	26.5(16.7%)	133.2(34.8%)
2002.04.18	Sp	R2	13.5	*Licmophora abbreviata*	13.5	7.96	8.0	1.27	12.0	13.33	0.88	3.75	24.1(22.0%)	51.5(16.1%)
2005.02.15	W	L1	13.5	*Gymnodinium sp.*	14.0	8.27	9.4	0.74	2.7	6.55	0.30	2.61	0.7(20.4%)	4.7(36.8%)
2007.02.06	W	L2	13.5	*Thalassiosira sp.*	13.0	8.12	8.6	0.69	17.3	9.61	0.32	2.14	2.7(25.8%)	7.0(31.8%)
2007.02.06	W	ref	13.5	*Thalassiosira sp.*	14.0	8.10	8.4	0.90	16.5	10.33	0.19	3.07	1.6(41.7%)	4.0(36.4%)
2003.01.21	W	R2	13.6	*Guinardia flaccida*	13.0	8.14	8.7	1.50	7.8	11.85	0.99	4.32	5.1(26.7%)	15.4(23.0%)
2007.02.06	W	C1	13.6	*Prorocentrum micans*	13.0	8.14	8.1	0.68	16.2	7.76	0.29	1.64	1.0(17.4%)	3.0(16.7%)
2007.02.06	W	In	13.7	*Thalassiosira sp.*	6.0	8.15	8.3	0.64	16.4	10.90	0.32	3.21	2.7(27.7%)	7.0(25.0%)
2004.04.28	Sp	ref	13.8	*Cerataulina pelagica*	2.0	8.29	8.8	0.58	9.6	3.36	0.26	0.69	70.4(84.5%)	121.3(79.7%)
2004.04.28	Sp	C2	13.9	*Cerataulina pelagica*	7.0	8.29	8.7	0.69	6.3	3.13	0.22	0.72	26.5(32.7%)	45.7(54.5%)
2003.04.22	Sp	R1	14.0	*Leptocylindrus danicus*	5.5	8.11	8.1	1.79	4.8	1.30	0.24	1.47	111.7(74.6%)	1015.2(86.4%)
2009.02.02	W	R1	14.0	*Thalassiosira sp.*	10.0	8.27	7.8	2.19	4.7	12.82	0.45	8.42	0.4(85.5%)	1.0(33.3%)
1999.02.09	W	R2	14.1	*Paralia sulcata*	9.0	8.03	8.6	1.08	8.0	4.30	0.84	4.20	9.6(27.2%)	19.2(23.9%)
2003.04.22	Sp	L2	14.1	*Leptocylindrus danicus*	11.0	8.12	8.1	1.81	5.2	1.49	1.61	1.45	83.6(67.1%)	759.8(76.1%)
2004.04.28	Sp	In	14.2	*Cerataulina pelagica*	1.5	8.27	8.4	0.73	12.0	2.12	0.17	0.74	112.7(83.1%)	194.3(78.5%)
2004.04.28	Sp	R2	14.3	*Cerataulina pelagica*	1.8	8.28	9.2	0.79	10.8	3.36	0.26	0.81	57.9(84.3%)	99.9(78.3%)
2000.04.25	Sp	C1	14.4	*Ditylum brightwellii*	10.0	8.03	6.9	1.15	10.0	6.20	0.25	4.91	136.9(53.6%)	141.6(36.1%)
2002.04.18	Sp	dis	14.4	*Licmophora abbreviata*	5.8	7.82	6.6	1.64	6.0	13.54	0.86	3.67	35.2(41.0%)	45.2(26.7%)
2004.04.28	Sp	L2	14.4	*Cerataulina pelagica*	2.0	8.30	8.5	1.09	10.6	3.19	0.22	0.77	53.0(46.4%)	91.4(49.3%)
2007.02.06	W	L1	14.4	*Thalassiosira sp.*	13.0	8.15	8.5	0.84	17.0	10.90	0.52	1.57	1.6(36.7%)	4.0(28.6%)
2007.05.03	Sp	R1	14.4	*Chaetoceros decipiens*	9.0	8.26	7.9	0.97	8.5	0.85	0.23	0.57	7.6(53.1%)	42.0(66.7%)
2001.02.13	W	dis	14.7	*Paralia sulcata*	6.5	8.22	7.7	1.53	21.0	12.36	1.11	8.16	8.4(32.3%)	16.8(28.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2002.04.18	Sp	R1	14.7	*Paralia sulcata*	7.0	7.99	7.0	2.12	16.0	13.78	0.90	4.24	27.8(32.6%)	55.6(31.4%)
2003.01.21	W	R1	14.7	*Guinardia flaccida*	10.5	8.07	8.3	1.72	2.9	12.50	1.58	2.90	4.9(25.4%)	14.8(22.3%)
2006.02.15	W	dis	14.9	*Navicula sp.*	6.0	7.46	8.6	1.05	5.3	6.54	0.70	3.40	1.1(28.7%)	2.1(40.0%)
2008.04.22	Sp	In	14.9	*Gymnodinium sp.*	6.0	8.18	8.0	0.88	7.8	2.31	0.10	1.93	0.5(43.9%)	1.0(33.3%)
2009.05.09	Sp	C2	14.9	*Gymnodinium sp.*	9.0	8.48	7.9	1.14	12.1	9.97	0.29	2.28	1.0(18.9%)	2.0(12.5%)
2001.05.09	Sp	In	15.0	*Licmophora abbreviata*	6.0	8.25	9.4	2.12	23.0	8.82	0.53	3.35	15.0(20.8%)	40.8(22.1%)
2008.04.22	Sp	C2	15.1	*Detonula pumila*	11.0	8.17	8.3	0.74	4.8	1.64	0.03	1.71	1.5(35.6%)	3.0(33.3%)
2009.05.09	Sp	ref	15.1	*Gymnodinium sp.*	8.0	8.48	8.0	0.86	11.0	6.77	0.29	4.36	2.0(41.5%)	4.0(22.2%)
2001.05.09	Sp	L1	15.2	*Ditylum brightwellii*	9.0	8.23	9.7	2.06	23.0	9.76	0.34	1.95	29.3(31.2%)	40.8(21.9%)
2003.04.22	Sp	C1	15.2	*Leptocylindrus danicus*	13.0	8.05	7.9	2.28	4.4	1.24	0.70	1.48	56.6(46.4%)	514.4(64.9%)
2003.04.22	Sp	R2	15.2	*Leptocylindrus danicus*	6.0	8.08	8.3	1.18	7.0	1.16	0.55	1.46	101.9(75.3%)	925.9(83.3%)
2004.04.28	Sp	R1	15.2	*Cerataulina pelagica*	1.8	8.26	7.7	0.93	9.3	3.36	0.23	0.83	61.9(66.6%)	106.7(57.4%)
2008.01.29	W	R1	15.2	*Gymnodinium sp.*	13.0	8.02	7.7	0.98	8.8	8.97	0.29	4.14	0.5(74.9%)	1.0(50.0%)
1999.02.09	W	R1	15.3	*Ditylum brightwellii*	4.4	8.14	8.8	0.93	9.0	4.09	0.81	5.19	39.1(63.2%)	18.0(26.3%)
2004.02.04	W	dis	15.3	*Thalassiosira sp.*	6.0	8.10	9.6	1.43	10.2	10.90	0.38	1.48	35.1(44.7%)	297.5(52.3%)
1999.02.09	W	dis	15.4	*Ceratium tripos*	4.0	8.10	8.7	0.73	10.0	5.75	0.86	5.80	8.8(22.7%)	13.2(18.6%)
2002.02.05	W	dis	15.4	*Rhizosolenia alata*	5.5	7.85	8.6	1.01	9.0	11.95	0.93	6.66	10.9(16.4%)	31.3(16.3%)
2005.02.15	W	C1	15.4	*Gymnodinium sp.*	16.0	8.28	11.5	0.38	8.0	4.55	0.24	4.80	1.2(30.0%)	6.8(42.9%)
2001.05.09	Sp	L2	15.5	*Licmophora abbreviata*	12.0	8.28	9.3	1.96	23.0	10.40	0.63	2.23	13.1(14.1%)	44.4(24.3%)
2005.04.19	Sp	R1	15.5	*Thalassiosira rotula*	8.0	8.25	10.9	1.45	4.7	2.60	0.34	3.24	14.2(15.8%)	132.8(30.3%)
2009.05.09	Sp	In	15.5	*Gymnodinium sp.*	11.0	8.51	8.1	1.18	16.3	6.77	0.29	2.21	1.0(31.3%)	2.0(18.2%)
2009.05.09	Sp	L2	15.5	*Licmophora paradoxa*	10.0	8.51	8.0	1.18	13.0	10.68	0.29	3.71	0.8(17.2%)	2.0(15.4%)
2000.04.25	Sp	R2	15.6	*Gonyaulax spinifera*	6.0	8.02	6.6	1.21	12.0	6.23	0.26	4.80	43.5(20.6%)	254.4(32.7%)
2006.05.07	Sp	In	15.6	*Leptocylindrus danicus*	7.0	8.14	9.5	0.71	7.8	1.05	0.26	1.61	9.5(43.7%)	86.1(46.0%)
2007.05.03	Sp	dis	15.6	*Prorocentrum micans*	6.0	8.21	7.9	0.94	9.4	1.57	0.13	1.07	2.0(37.6%)	7.0(46.7%)
2008.04.22	Sp	ref	15.8	*Thalassiosira sp.*	11.0	8.15	8.3	0.90	5.1	0.75	0.06	2.07	1.9(31.5%)	5.0(31.3%)
2009.05.09	Sp	R1	15.9	*Gymnodinium sp.*	10.0	8.41	7.8	1.22	10.7	9.26	0.36	3.00	1.0(13.8%)	2.0(11.1%)
2009.05.09	Sp	R2	16.0	*Gymnodinium sp.*	9.0	8.45	7.7	1.14	9.4	8.90	0.32	4.43	1.0(16.1%)	2.0(12.5%)
2001.05.09	Sp	R2	16.1	*Coscinodiscus granii*	7.0	8.18	9.6	1.63	23.0	5.86	0.24	3.30	7.7(14.7%)	21.6(14.3%)
2009.02.02	W	dis	16.1	*Navicula sp.*	10.0	8.22	7.7	1.55	6.4	13.17	0.52	7.43	0.5(51.8%)	1.0(50.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2009.05.09	Sp	L1	16.1	*Gymnodinium sp.*	10.0	8.48	7.9	1.14	11.2	9.61	0.29	3.71	1.0(16.2%)	2.0(14.3%)
2001.05.09	Sp	ref	16.2	*Licmophora abbreviata*	8.0	8.25	9.1	2.07	23.0	5.26	0.14	2.84	15.9(18.5%)	50.4(29.8%)
2008.04.22	Sp	L1	16.2	*Euglena sp.*	9.0	8.19	7.9	0.83	4.5	4.27	0.13	2.28	0.5(58.2%)	2.0(66.7%)
2007.02.06	W	R1	16.3	*Thalassiosira sp.*	13.0	8.11	7.9	0.94	18.1	10.61	0.68	2.57	1.2(57.2%)	3.0(42.9%)
2000.04.25	Sp	R1	16.4	*Ditylum brightwellii*	6.0	8.00	7.6	1.10	12.0	6.03	0.18	5.95	9.8(15.0%)	121.2(41.4%)
2006.11.16	A	ref	16.4	*Scrippsiella trochoidea*	2.0	8.03	6.4	0.77	7.5	5.39	0.53	10.04	0.6(19.9%)	2.6(21.4%)
2001.11.07	A	In	16.5	*Coscinodiscus centrialis*	8.0	8.13	7.4	1.32	7.0	9.90	0.17	13.92	7.7(17.4%)	54.0(26.3%)
2009.05.09	Sp	C1	16.5	*Gymnodinium sp.*	10.0	8.46	7.8	1.18	13.2	10.33	0.32	3.00	2.0(36.3%)	4.0(23.5%)
2001.05.09	Sp	C1	16.6	*Ditylum brightwellii*	12.0	8.20	9.2	1.58	21.0	10.81	0.12	2.62	29.3(26.9%)	48.0(24.0%)
2006.11.16	A	R1	16.7	*Ceratiumfusus*	1.5	8.10	5.8	0.93	5.1	10.97	0.42	10.41	1.1(29.4%)	2.0(22.5%)
2008.04.22	Sp	C1	16.7	*Gymnodinium sp.*	11.0	8.16	8.1	0.86	4.1	2.03	0.13	1.71	1.5(51.2%)	3.0(42.9%)
2001.05.09	Sp	C2	16.9	*Guinardia flaccida*	12.0	8.17	8.7	1.69	25.0	9.86	0.19	3.04	49.2(38.8%)	28.8(12.2%)
2006.11.16	A	C2	16.9	*Ceratium fusus*	2.0	8.10	5.8	0.58	4.6	3.08	0.71	7.52	1.1(26.5%)	3.7(26.7%)
2004.04.28	Sp	C1	17.0	*Cerataulina pelagica*	2.0	8.25	8.2	1.36	8.1	3.14	0.17	0.72	45.7(70.2%)	78.7(76.5%)
2006.11.16	A	C1	17.0	*Ceratium fusus*	2.0	8.12	6.5	0.47	5.5	8.73	0.52	9.70	2.1(34.5%)	7.1(33.3%)
2002.11.05	A	ref	17.2	*Gymnodinium sp.*	8.0	8.08	7.6	0.88	11.0	15.92	0.39	7.51	7.5(53.5%)	15.1(34.0%)
2002.07.23	Su	In	17.3	*Gymnodinium sp.*	4.0	8.08	7.2	2.21	4.0	10.22	0.24	3.19	3.8(50.4%)	7.5(34.7%)
2002.07.23	Su	L2	17.4	*Gymnodinium sp.*	11.0	8.03	7.6	0.84	7.0	12.52	0.40	13.74	5.3(57.6%)	10.6(40.0%)
2002.11.05	A	L2	17.4	*Gymnodinium sp.*	13.0	8.05	7.7	1.07	9.0	16.43	0.41	5.78	3.9(42.3%)	7.7(25.0%)
2002.07.23	Su	L1	17.5	*Gymnodinium sp.*	15.0	8.07	8.2	1.53	7.0	10.12	0.49	5.73	4.7(50.0%)	9.4(39.1%)
2000.04.25	Sp	dis	17.6	*Gonyaulax spinifera*	6.0	7.98	6.7	1.45	11.0	6.08	0.27	5.45	21.8(18.9%)	132.0(44.7%)
2003.07.22	Su	In	17.6	*Gymnodinium sp.*	6.0	7.92	7.9	1.23	5.6	3.75	0.50	2.85	14.3(58.0%)	28.5(33.6%)
2001.11.07	A	L2	17.7	*Ditylum brightwellii*	10.5	7.88	7.5	1.26	6.0	1.52	0.33	14.03	9.8(24.8%)	48.0(25.5%)
2001.11.07	A	R2	17.7	*Coscinodisucus sp.*	10.5	8.11	6.8	0.99	9.0	6.96	0.00	7.16	5.8(12.9%)	42.0(24.3%)
2001.05.09	Sp	R1	17.8	*Ditylum brightwellii*	10.0	8.28	9.3	1.36	24.0	6.91	0.50	3.62	39.1(38.7%)	49.2(26.1%)
2001.11.07	A	C2	17.8	*Coscinodisucus sp.*	12.0	8.07	6.8	1.75	6.0	11.81	0.01	8.32	11.6(25.6%)	31.2(21.8%)
2002.11.05	A	In	17.8	*Gymnodinium sp.*	4.5	8.05	7.8	0.67	11.0	15.25	0.22	3.77	4.8(27.5%)	9.7(18.7%)
2002.11.05	A	L1	17.8	*Gymnodinium sp.*	7.0	7.88	8.7	1.33	15.0	15.36	0.18	4.20	5.0(39.4%)	9.9(23.5%)
2004.04.28	Sp	dis	17.8	*Cerataulina pelagica*	1.6	8.23	7.8	0.27	10.6	2.57	0.20	0.80	54.1(71.9%)	93.3(65.4%)
2006.08.17	Su	L1	17.8	*Alexandrium sp.*	10.0	8.14	8.6	1.19	9.3	2.84	0.42	5.64	3.8(30.6%)	5.2(16.5%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2008.01.29	W	dis	17.8	*Gymnodinium sp.*	8.0	7.95	8.3	0.73	6.5	9.12	0.36	6.43	0.5(36.0%)	1.0(33.3%)
2001.11.07	A	ref	17.9	*Coscinodiscus granii*	11.0	8.07	6.6	1.58	11.0	4.24	0.02	11.05	7.7(26.0%)	40.8(33.3%)
2003.01.21	W	C2	17.9	*Gymnodinium sp.*	17.0	8.18	8.9	1.37	5.3	11.71	0.94	4.21	2.2(28.1%)	12.2(35.7%)
2003.01.21	W	dis	17.9	*Paralia sulcata*	3.5	7.98	8.4	1.42	5.5	12.36	1.11	4.32	6.1(26.0%)	21.4(26.4%)
2005.10.27	A	ref	17.9	*Gymnodinium sp.*	11.0	8.25	8.6	0.49	2.7	3.13	0.12	0.91	1.0(29.7%)	2.0(25.0%)
2001.11.07	A	L1	18.0	*Guinardia flaccida*	12.5	8.13	7.4	1.67	18.0	1.48	0.01	4.36	12.3(31.5%)	40.8(40.0%)
2000.10.24	A	L1	18.1	*Paralia sulcata*	12.0	7.89	7.7	1.19	11.0	10.29	0.21	6.00	18.6(25.6%)	54.0(23.9%)
2003.07.22	Su	L2	18.1	*Gymnodinium sp.*	12.0	7.88	7.6	1.42	8.7	3.11	0.17	2.35	33.8(67.7%)	67.5(50.5%)
2002.11.05	A	R2	18.2	*Gymnodinium sp.*	5.0	8.08	8.5	1.64	5.0	14.06	0.52	3.91	5.4(52.9%)	10.7(32.6%)
2002.07.23	Su	C2	18.3	*Gymnodinium sp.*	13.0	7.97	7.7	1.61	7.0	11.42	0.51	5.84	2.7(22.1%)	8.1(19.6%)
2003.07.22	Su	L1	18.3	*Gymnodinium sp.*	11.0	7.86	8.0	1.04	4.2	3.22	0.29	2.50	27.8(68.0%)	55.5(51.7%)
2007.11.14	A	ref	18.3	*Thalassiosira sp.*	11.5	8.16	7.6	1.66	16.9	7.69	0.23	1.29	1.2(87.9%)	3.0(60.0%)
2002.11.05	A	C1	18.4	*Gymnodinium sp.*	12.0	8.06	7.8	1.24	8.0	16.10	0.38	5.06	5.3(59.2%)	10.5(39.4%)
2005.10.27	A	In	18.4	*Gymnodinium sp.*	8.0	8.23	8.3	0.87	9.6	3.12	0.17	0.95	1.3(45.2%)	3.3(41.9%)
2002.07.23	Su	C1	18.5	*Gymnodinium splendens*	13.0	8.03	7.8	1.48	6.0	12.15	0.37	8.77	2.0(31.3%)	6.3(25.2%)
2003.07.22	Su	C2	18.5	*Gymnodinium sp.*	14.0	7.85	8.1	1.32	4.1	4.40	0.50	3.19	30.0(78.7%)	59.9(58.8%)
2009.10.21	A	L1	18.5	*Guinardia flaccida*	9.0	8.09	7.5	1.27	6.1	4.63	0.16	2.21	5.1(24.1%)	7.0(21.9%)
2000.10.24	A	In	18.6	*Ditylum brightwellii*	8.0	8.00	6.8	1.34	19.0	8.77	0.18	5.94	29.3(32.5%)	28.8(15.2%)
2000.10.24	A	L2	18.6	*Paralia sulcata*	13.0	8.04	7.6	1.22	18.0	9.16	0.20	5.37	15.6(29.4%)	39.6(22.6%)
2009.10.21	A	In	18.6	*Guinardia striata*	9.0	8.08	7.2	1.19	8.1	5.34	0.36	6.43	7.7(31.3%)	12.0(26.7%)
2001.11.07	A	C1	18.7	*Protoperidinium sp.*	11.0	8.10	6.7	1.48	8.0	0.82	0.00	4.23	7.8(16.7%)	48.0(31.5%)
2009.10.21	A	L2	18.7	*Gymnodinium sp.*	9.0	8.06	7.5	1.07	8.2	5.70	0.23	3.00	6.0(67.3%)	12.0(40.0%)
1999.08.05	Su	In	18.8	*Dinophysis caudata*	4.8	8.03	8.2	0.85	10.0	10.87	0.40	4.15	50.7(43.9%)	38.4(18.8%)
1999.08.05	Su	R2	18.8	*Dinophysis caudata*	4.0	8.01	8.3	0.82	12.0	7.20	0.22	3.20	90.3(55.3%)	68.4(27.4%)
2000.10.24	A	ref	18.8	*Paralia sulcata*	12.0	7.90	6.7	1.06	18.0	10.33	0.19	5.64	19.8(23.6%)	61.2(20.3%)
2001.11.07	A	R1	18.8	*Protoperidinium sp.*	11.0	8.08	6.8	1.46	8.0	3.42	0.08	17.73	5.2(14.6%)	31.2(21.5%)
2002.11.05	A	C2	18.8	*Gymnodinium sp.*	14.0	8.09	8.5	1.39	6.0	17.17	0.36	3.88	7.4(60.5%)	14.9(41.2%)
2006.08.17	Su	C1	18.8	*Protoperidinium pellagicum*	12.0	8.12	8.0	1.23	7.4	3.39	0.37	6.34	6.6(37.8%)	5.6(18.9%)
2002.07.23	Su	R2	18.9	*Gymnodinium sp.*	12.0	8.11	7.2	1.47	7.0	11.92	0.35	7.86	5.5(52.8%)	10.9(39.7%)
2005.10.27	A	L1	18.9	*Gymnodinium sp.*	10.5	8.25	7.9	0.78	2.3	3.84	0.19	0.85	1.5(51.0%)	3.0(30.8%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2006.08.17	Su	In	18.9	*Protoperidinium pellagicum*	7.0	8.18	8.2	1.22	4.6	2.41	0.39	5.52	4.2(26.7%)	7.2(20.1%)
2007.11.14	A	In	18.9	*Ditylum brightwellii*	5.5	8.16	7.9	1.42	15.7	6.27	0.23	1.57	8.2(77.5%)	6.0(75.0%)
2003.07.22	Su	R2	19.0	*Gymnodinium sp.*	10.0	7.86	7.6	1.32	4.1	3.52	0.26	3.12	26.1(65.7%)	52.2(49.7%)
2007.11.14	A	L1	19.0	*Thalassiosira sp.*	10.0	8.14	7.4	1.73	15.9	5.87	0.26	1.57	1.2(80.3%)	3.0(60.0%)
2008.04.22	Sp	R1	19.0	*Euglena sp.*	11.0	8.19	8.6	0.89	6.7	2.24	0.16	1.50	1.6(35.5%)	6.0(50.0%)
2008.10.21	A	In	19.1	*Gymnodinium sp.*	4.0	8.06	8.0	0.64	6.1	5.63	0.39	1.93	1.0(26.9%)	5.0(25.0%)
1999.08.05	Su	ref	19.2	*Dinophysis caudata*	6.0	8.07	8.4	0.72	10.0	11.67	0.25	4.31	33.3(29.3%)	38.4(21.5%)
2002.11.05	A	R1	19.2	*Gymnodinium sp.*	7.2	8.09	9.0	1.01	7.0	15.00	0.42	7.38	5.2(52.4%)	10.5(35.6%)
2008.10.21	A	L1	19.2	*Guinardia striata*	5.5	8	7.4	0.59	6.2	6.12	0.52	3.14	5.1(59.1%)	6.0(31.6%)
2009.10.21	A	C2	19.2	*Gymnodinium sp.*	11.5	8.05	7.4	1.19	6.7	4.98	0.19	2.93	8.5(73.6%)	17.0(56.7%)
2009.10.21	A	ref	19.2	*Guinardia flaccida*	13.0	8.11	7.5	0.91	5.8	4.27	0.23	4.36	5.1(43.3%)	8.0(36.4%)
2003.07.22	Su	C1	19.3	*Gymnodinium sp.*	12.0	7.86	7.7	1.14	8.7	3.71	0.40	2.12	16.9(65.6%)	33.9(39.4%)
2005.10.27	A	C2	19.3	*Gymnodinium sp.*	12.0	8.26	8.5	0.76	6.8	4.12	0.17	1.22	1.4(35.3%)	2.8(22.9%)
2003.07.22	Su	R1	19.4	*Gymnodinium sp.*	8.0	7.83	7.4	1.23	3.2	3.30	0.21	2.92	25.4(67.1%)	50.8(51.3%)
2007.11.14	A	C2	19.4	*Thalassiosira sp.*	12.0	8.15	7.8	1.53	13.2	2.74	0.26	1.50	0.4(90.6%)	1.0(50.0%)
1999.08.05	Su	L1	19.5	*Dinophysis caudata*	4.0	8.03	7.8	0.93	11.0	7.99	0.33	4.03	49.1(34.5%)	43.2(21.8%)
2000.10.24	A	C2	19.5	*Ditylum brightwellii*	12.0	8.01	6.8	0.83	18.0	9.56	0.20	5.30	39.1(37.3%)	49.2(20.4%)
2005.07.12	Su	L1	19.5	*Dinophysis forthii*	1.8	8.13	8.3	1.24	4.2	7.42	0.22	1.12	5.3(15.3%)	171.0(61.7%)
2007.11.14	A	R1	19.5	*Thalassiosira sp.*	10.0	8.16	7.6	1.71	14.8	2.49	0.13	1.14	1.6(72.8%)	4.0(66.7%)
1999.08.05	Su	C2	19.6	*Dinophysis caudata*	5.0	7.94	8.1	0.77	12.0	7.74	0.51	3.51	53.9(41.6%)	49.6(24.0%)
1999.08.05	Su	R1	19.6	*Dinophysis caudata*	4.0	8.02	8.4	1.01	11.0	10.13	0.25	3.61	66.8(61.1%)	76.8(33.3%)
2004.10.19	A	In	19.6	*Alexandrium sp.*	5.2	8.15	7.4	1.16	1.8	7.07	0.43	4.84	1.0(27.4%)	0.8(12.5%)
2004.10.19	A	L1	19.6	*Rhizosolenia sp.*	14.0	8.15	7.2	1.23	4.2	7.89	0.34	4.86	0.8(55.8%)	1.6(66.7%)
1999.08.05	Su	L2	19.7	*Dinophysis caudata*	6.0	7.98	8.6	0.88	9.0	9.30	0.45	4.17	36.4(30.6%)	43.2(26.5%)
2005.02.15	W	dis	19.7	*Coscinodisucus oculusiridis*	7.0	8.23	8.9	0.94	2.4	6.37	0.22	3.65	1.1(24.9%)	4.7(41.2%)
2002.07.23	Su	R1	19.8	*Gymnodinium sp.*	11.0	7.99	7.3	1.85	3.0	8.85	0.64	5.90	4.9(47.9%)	9.7(33.9%)
2002.07.23	Su	ref	19.8	*Gymnodinium sp.*	13.0	8.13	7.6	1.78	4.0	10.13	0.46	7.82	5.3(40.1%)	10.7(28.7%)
2005.07.12	Su	In	19.8	*Chaetoceros debilis*	3.0	8.11	8.1	1.23	10.5	6.81	0.25	1.35	6.3(17.2%)	138.5(50.8%)
2008.10.21	A	C1	19.8	*Pseudo-nitzchia spp.*	6.0	8.03	7.6	0.72	4.2	6.09	0.77	1.57	1.0(23.7%)	5.0(23.8%)
2004.10.19	A	C1	19.9	*Protoperidinium breve*	14.0	8.17	7.1	1.23	7.2	7.75	0.50	6.12	1.4(41.8%)	2.6(33.3%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2005.07.12	Su	C1	19.9	*Chaetoceros debilis*	3.0	8.12	8.2	1.45	9.6	4.95	0.23	1.41	4.7(14.6%)	88.0(39.6%)
2006.11.16	A	L1	19.9	*Nitzschia sp.*	1.5	8.09	5.7	0.76	5.7	5.29	0.58	7.45	1.8(34.7%)	3.6(22.2%)
2008.10.21	A	C2	19.9	*Guinardia striata*	9.0	8.05	7.6	0.73	5.5	4.06	0.42	2.14	2.6(55.0%)	3.0(21.4%)
2004.10.19	A	L2	20.0	*Protoperidinium breve*	15.0	8.17	7.1	1.16	4.6	6.04	0.48	5.53	1.3(45.4%)	1.8(42.9%)
2005.07.12	Su	C2	20.0	*Chaetoceros socialis*	2.0	8.14	8.1	1.28	6.9	4.68	0.22	2.26	7.2(19.2%)	238.5(70.8%)
2007.02.06	W	dis	20.0	*Thalassiosira sp.*	7.3	8.07	7.6	0.81	15.3	7.55	0.32	1.93	1.6(33.7%)	4.0(26.7%)
1999.08.05	Su	C1	20.1	*Dinophysis caudata*	5.0	8.01	8.4	0.91	10.0	8.86	0.31	4.22	73.1(44.4%)	55.4(27.8%)
2001.08.01	Su	C1	20.1	*Ditylum brightwellii*	5.0	7.99	8.7	0.98	8.0	1.83	0.05	8.50	48.9(35.6%)	50.4(17.4%)
2003.10.07	A	In	20.1	*Pseudo-nitzschiasmata*	5.0	8.05	8.2	0.74	5.0	5.95	0.35	3.18	78.4(56.3%)	156.9(39.4%)
2006.11.16	A	In	20.1	*Paralia sulcata*	1.5	8.11	6.3	0.87	4.8	3.33	0.62	13.46	1.3(12.9%)	3.5(12.5%)
2001.08.01	Su	In	20.2	*Ceratium tripos*	5.5	8.07	8.8	1.72	12.0	14.90	0.00	2.87	8.8(10.4%)	56.4(19.8%)
2006.08.17	Su	R1	20.2	*Protoperidinium pellagicum*	9.0	8.16	7.5	1.26	3.9	2.97	0.26	5.61	3.0(24.3%)	9.2(26.3%)
2006.08.17	Su	ref	20.2	*Alexandrium tamarensis*	11.0	8.17	7.5	0.98	4.1	2.86	0.30	6.18	2.8(24.0%)	6.8(23.7%)
2003.04.22	Sp	dis	20.3	*Leptocylindrus danicus*	3.5	7.97	7.6	2.36	8.1	1.66	0.27	2.08	69.6(59.0%)	633.0(77.1%)
2006.08.17	Su	dis	20.3	*Alexandrium tamarensis*	8.0	8.09	7.6	1.16	6.1	2.29	0.42	7.31	1.0(15.1%)	3.2(14.6%)
2007.07.19	Su	L1	20.3	*Thalassiosira sp.*	11.0	8.2	7.3	1.32	11.1	5.27	0.10	1.64	0.4(100.0%)	1.0(100.0%)
2007.07.19	Su	ref	20.3	*Thalassiosira sp.*	11.0	8.22	7.5	1.66	8.1	4.95	0.06	1.43	0.4(100.0%)	1.0(100.0%)
2008.10.21	A	ref	20.3	*Bacteriastrum hyalinum*	7.0	8.05	7.4	0.61	5.0	5.59	0.61	2.14	2.5(30.9%)	6.0(18.2%)
2001.08.01	Su	ref	20.4	*Ditylum brightwellii*	6.0	8.19	7.5	1.57	11.0	7.75	0.01	6.97	39.1(37.2%)	38.4(14.9%)
2003.10.07	A	C1	20.4	*Pseudo-nitzschiasmata*	13.0	8.14	7.4	0.74	2.7	5.31	0.32	3.96	24.7(34.0%)	49.3(29.3%)
2005.07.12	Su	ref	20.4	*Dinophysis forthii*	4.3	8.10	8.0	1.18	7.5	2.66	0.22	1.31	7.3(20.7%)	153.5(58.7%)
2007.07.19	Su	C2	20.4	*Thalassiosira sp.*	13.0	8.23	7.5	1.46	10.9	5.87	0.13	1.21	0.8(100.0%)	2.0(100.0%)
2009.10.21	A	C1	20.4	*Gymnodinium sp.*	10.0	8.07	7.3	1.11	7.7	5.34	0.16	3.64	2.5(18.3%)	7.0(15.9%)
2009.10.21	A	R2	20.4	*Gymnodinium sp.*	10.0	8.06	7.1	0.99	6.8	4.63	0.16	2.93	7.0(53.9%)	14.0(40.0%)
1999.10.02	A	In	20.6	*Paralia sulcata*		8.08	9.3	0.90	12.0	9.37	0.18	4.18	10.2(27.9%)	20.4(18.1%)
2004.10.19	A	ref	20.6	*Rhizosolenia alata*	12.0	8.17	7.3	1.19	3.9	6.30	0.26	4.21	0.3(26.2%)	0.6(18.8%)
2007.07.19	Su	In	20.6	*Thalassiosira sp.*	4.0	8.21	7.7	1.68	9.0	3.95	0.13	1.50	0.8(100.0%)	2.0(100.0%)
2001.05.09	Sp	dis	20.7	*Prorocentrum micans*	8.0	8.11	8.6	1.69	25.0	9.23	1.01	3.19	34.8(27.5%)	37.2(18.3%)
2001.08.01	Su	L1	20.7	*Chaetoceros compressus*	5.0	8.16	8.8	1.80	9.0	11.35	0.01	6.93	15.6(17.5%)	109.2(27.7%)
2001.08.01	Su	L2	20.7	*Ceratium furca*	5.0	8.21	8.5	0.86	9.0	10.02	0.05	3.98	18.0(15.5%)	88.8(27.8%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2003.10.07	A	C2	20.7	*Pseudo-nitzschia smata*	14.0	8.09	7.7	1.23	6.6	6.90	0.19	3.10	77.4(45.2%)	154.7(43.1%)
2003.10.07	A	L2	20.7	*Pseudo-nitzschia smata*	11.0	8.15	7.7	1.03	5.0	6.50	0.38	2.80	21.5(28.8%)	50.1(24.9%)
2004.10.19	A	C2	20.7	*Protoperidinium brochii*	14.0	8.19	7.3	1.34	4.7	6.73	0.30	4.14	1.8(68.6%)	1.6(50.0%)
2005.10.27	A	C1	20.7	*Gymnodinium sp.*	11.0	8.24	8.0	0.91	2.9	0.90	0.17	0.98	2.0(28.0%)	4.0(22.9%)
2009.10.21	A	R1	20.7	*Gymnodinium sp.*	10.0	8.04	7.0	1.11	6.6	4.63	0.19	2.21	9.5(58.0%)	19.0(41.3%)
2000.07.25	Su	C2	20.8	*Ditylum brightwellii*	16.0	7.56	8.4	0.87	5.0	7.75	0.25	5.00	9.8(19.8%)	25.2(23.9%)
2000.07.25	Su	ref	20.8	*Dictyocha fibula*	16.0	8.14	7.8	1.35	2.0	8.72	0.28	5.33	67.3(59.0%)	122.4(50.0%)
2001.08.01	Su	C2	20.8	*Chaetoceros compressus*	4.8	8.16	8.4	1.52	6.0	9.78	0.00	4.79	9.6(14.1%)	67.2(28.4%)
2007.11.14	A	C1	20.8	*Thalassiosira sp.*	11.0	8.13	7.7	2.19	15.4	9.83	0.32	1.36	1.2(79.0%)	3.0(60.0%)
2009.05.09	Sp	dis	20.8	*Gymnodinium sp.*	12.0	8.31	7.1	1.06	13.1	8.19	0.36	5.21	1.0(17.3%)	3.0(16.7%)
1999.08.05	Su	dis	20.9	*Dinophysis caudata*	5.0	8.06	8.0	1.28	12.0	10.53	0.29	5.08	99.8(46.9%)	75.6(27.6%)
1999.10.02	A	L2	20.9	*Ditylum brightwellii*		8.11	8.7	0.80	11.0	8.90	0.22	4.11	9.8(18.3%)	19.2(18.8%)
2000.10.24	A	R2	20.9	*Ditylum brightwellii*	12.0	7.92	6.7	0.95	17.0	8.95	0.20	5.12	29.3(31.1%)	32.4(19.7%)
2003.10.07	A	L1	20.9	*Pseudo-nitzschiasmata*	8.0	8.21	8.6	0.64	5.5	5.76	0.43	3.49	47.9(42.8%)	95.9(41.0%)
2008.04.22	Sp	dis	20.9	*Thalassiosira sp.*	6.0	8.14	7.4	0.71	5.3	1.99	0.23	2.21	1.2(47.0%)	3.0(42.9%)
1999.10.02	A	R1	21.0	*Paraliasulcata*		8.17	9.2	1.02	12.0	9.50	0.23	4.21	18.6(33.6%)	37.2(27.4%)
2003.10.07	A	R1	21.0	*Pseudo-nitzschiasmata*	5.5	8.12	7.4	1.11	6.3	6.10	0.39	2.76	46.7(43.8%)	93.3(36.0%)
2004.10.19	A	R2	21.0	*Rhizosolenia setigera*	13.0	8.19	7.3	1.23	6.4	6.78	0.26	4.68	1.5(63.4%)	1.9(42.9%)
1999.10.02	A	ref	21.1	*Ditylum brightwellii*		8.14	9.0	0.78	12.0	8.56	0.29	4.33	9.8(25.3%)	21.6(23.4%)
2000.10.24	A	C1	21.1	*Paralia sulcata*	11.0	7.98	6.7	1.29	19.0	8.83	0.19	5.52	9.6(15.7%)	33.6(18.8%)
2000.07.25	Su	C1	21.2	*Protoperidinium pentagonum*	16.0	7.55	8.8	1.06	7.0	9.26	0.27	5.55	10.5(21.8%)	25.2(20.4%)
2001.08.01	Su	R1	21.2	*Protoperidinium pentagonum*	5.7	8.07	7.3	1.18	8.0	11.56	0.28	6.34	13.1(17.2%)	51.6(20.1%)
2003.10.07	A	ref	21.2	*Pseudo-nitzschia smata*	14.0	8.08	7.5	1.24	7.6	7.22	0.32	2.54	44.8(37.0%)	89.6(33.3%)
2007.07.19	Su	R1	21.2	*Thalassiosira sp.*	8.7	8.21	7.3	1.59	11.1	6.69	0.10	1.50	0.4(100.0%)	1.0(100.0%)
2008.10.21	A	R2	21.2	*Euglena sp.*	7.0	8.01	7.3	0.70	6.8	5.09	0.36	0.93	1.6(30.5%)	6.0(25.0%)
2000.07.25	Su	In	21.4	*Guinardia flaccida*	8.0	7.67	8.4	1.41	7.0	7.96	0.20	5.64	12.3(18.4%)	31.2(24.8%)
2007.07.19	Su	C1	21.4	*Thalassiosira sp.*	11.2	8.21	7.4	1.77	10.5	5.13	0.13	1.50	0.4(76.4%)	1.0(50.0%)
2001.08.01	Su	R2	21.5	*Eucampia zodiacus*	5.5	7.98	8.0	1.21	8.0	7.05	0.33	2.14	13.2(15.1%)	52.8(15.3%)
2002.07.23	Su	dis	21.5	*Gymnodinium sp.*	5.0	8.02	7.1	1.84	8.0	9.34	0.38	5.83	6.2(36.7%)	12.3(31.9%)
2007.07.19	Su	dis	21.5	*Thalassiosira sp.*	6.0	8.18	6.8	1.81	8.8	5.09	0.16	1.86	0.4(90.6%)	1.0(50.0%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2007.11.14	A	dis	21.5	*Thalassiosira sp.*	6.5	8.13	7.3	2.05	15.4	8.87	0.29	1.36	1.6(69.0%)	4.0(57.1%)
1999.10.02	A	R2	21.7	*Coscinodisucus sp.*		8.04	8.4	0.97	13.0	8.71	0.20	3.93	9.7(20.8%)	13.2(12.0%)
2000.07.25	Su	L2	21.7	*Protoperidinium pentagonum*	14.0	8.05	8.3	1.39	3.0	8.74	0.20	5.92	7.8(16.4%)	38.4(30.5%)
2006.08.17	Su	C2	21.7	*Protoperidinium pellagicum*	13.0	8.16	8.0	1.08	4.9	2.19	0.32	5.18	4.7(43.6%)	5.8(26.7%)
2000.07.25	Su	R2	21.8	*Ceratium tripos*	16.0	7.45	8.4	1.20	4.0	8.88	0.22	5.41	17.7(24.6%)	15.6(14.9%)
2003.07.22	Su	dis	21.8	*Gymnodinium sp.*	6.0	7.78	6.9	1.31	3.1	4.22	0.35	2.30	17.7(50.1%)	35.3(35.4%)
1999.10.02	A	C2	22.0	*Paralia sulcata*		8.06	8.9	0.88	13.0	8.91	0.17	3.80	13.8(29.7%)	27.6(23.2%)
2000.10.24	A	R1	22.0	*Ditylum brightwellii*	12.0	8.03	6.4	1.06	17.0	8.07	0.19	5.72	29.3(28.4%)	46.8(23.6%)
2001.11.07	A	dis	22.0	*Ditylum brightwellii*	8.5	8.03	6.6	0.98	8.0	3.11	0.04	8.29	39.1(60.2%)	20.4(20.5%)
2003.10.07	A	R2	22.0	*Pseudo-nitzschia smata*	6.0	8.05	7.9	0.79	8.0	6.38	0.26	3.38	52.0(44.7%)	104.0(38.2%)
2004.10.19	A	R1	22.1	*Rhizosolenia sp.*	14.0	8.15	6.9	1.45	6.4	6.58	0.29	4.54	0.8(27.5%)	4.2(45.5%)
1999.10.02	A	C1	22.2	*Paralia sulcata*		8.03	8.7	0.82	11.0	7.64	0.24	4.09	8.4(26.5%)	28.8(27.6%)
2004.08.04	Su	R1	22.3	*Gonyaulax sp.*	7.0	8.16	7.5	1.71	2.7	2.58	0.19	0.74	3.6(26.6%)	11.4(28.1%)
2005.10.27	A	R1	22.3	*Gymnodinium sp.*	6.0	8.22	8.1	1.24	7.1	8.01	0.12	1.02	1.4(36.6%)	2.8(27.5%)
2005.07.12	Su	R1	22.4	*Dinophysis forthii*	3.2	8.11	8.2	1.20	8.2	12.75	0.30	2.20	10.6(27.9%)	51.0(27.4%)
2008.10.21	A	R1	22.5	*Guinardia striata*	6.0	7.99	7.3	0.69	5.9	6.41	0.23	1.57	2.6(40.3%)	3.0(21.4%)
1999.10.02	A	dis	22.8	*Ditylum brightwellii*		8.11	8.6	1.06	14.0	8.15	0.25	4.46	19.6(43.3%)	22.8(23.2%)
2000.07.25	Su	L1	22.8	*Paralia sulcata*	14.0	7.60	7.7	1.51	3.0	8.43	0.26	5.38	7.8(24.1%)	26.4(25.0%)
2009.08.21	Su	L2	22.8	*Scrippsiella trochoidea*	9.0	8.27	7.1	1.07	6.1	8.55	0.23	2.93	10.1(20.6%)	22.0(14.7%)
2004.08.04	Su	L1	23.0	*Pseudo-nitzchia spp.*	7.0	8.14	7.7	1.69	2.0	3.41	0.22	1.40	5.5(50.8%)	11.0(37.5%)
2004.08.04	Su	ref	23.0	*Protoperidinium breve*	6.0	8.16	7.3	1.83	6.6	3.68	0.27	0.92	2.6(40.2%)	18.1(70.3%)
2009.08.21	Su	In	23.2	*Guinardia striata*	5.0	8.29	7.0	1.19	7.2	6.77	0.19	2.28	17.9(44.1%)	30.0(17.2%)
2004.08.04	Su	L2	23.3	*Pseudo-nitzchia spp.*	6.5	8.16	7.5	1.24	4.2	2.99	0.44	1.53	1.1(50.0%)	2.3(50.0%)
2009.08.21	Su	C1	23.3	*Guinardia flaccida*	6.0	8.28	6.8	1.11	5.3	6.77	0.19	2.28	2.6(14.6%)	19.0(24.7%)
2000.10.24	A	dis	23.4	*Ditylum brightwellii*	7.0	7.97	6.3	1.27	17.0	9.73	0.17	5.34	58.7(48.6%)	22.8(14.1%)
2008.07.29	Su	C1	23.4	*Gymnodinium sp.*	12.5	7.98	6.5	1.03	4.9	4.13	0.23	2.21	1.0(32.8%)	2.0(18.2%)
2000.07.25	Su	R1	23.5	*Ceratium tripos*	5.0	7.57	8.0	1.28	9.0	8.98	0.24	5.70	8.8(18.9%)	19.2(18.2%)
2002.11.05	A	dis	23.5	*Gymnodinium sp.*	4.5	8.02	7.5	1.24	7.0	15.95	0.51	5.41	5.5(38.7%)	10.9(27.5%)
2009.08.21	Su	L1	23.6	*Scrippsiella trochoidea*	4.0	8.29	6.8	1.27	5.6	12.11	0.26	3.00	3.4(15.0%)	18.0(21.7%)
2001.08.01	Su	dis	23.7	*Thalassiosira rotula*	5.0	8.15	7.2	1.83	9.0	5.77	0.02	13.94	19.5(15.7%)	54.0(16.2%)

(continued)

Date	season	St.	T (℃)	Top Dominant	Tr. (m)	pH	DO (mg L^{-1})	COD (mg L^{-1})	SS (mg L^{-1})	SiO_2 (umol L^{-1})	PO_4 (umol L^{-1})	NO_2+NO_3 (umol L^{-1})	Biomass (ng C mL^{-1})	Abundance (cells mL^{-1})
2008.10.21	A	dis	23.7	*Thalassiosira sp.*	6.0	7.97	7.0	0.82	4.7	8.15	0.48	1.71	1.2(36.2%)	3.0(25.0%)
2004.08.04	Su	C2	23.8	*Protoperidinium pellagicum*	8.0	8.20	7.5	1.59	2.6	2.30	0.06	1.14	2.4(41.0%)	14.2(52.3%)
2008.07.29	Su	C2	23.8	*Guinardia flaccida*	11.0	7.98	6.5	0.84	6.4	8.72	0.36	1.71	2.6(54.7%)	2.0(25.0%)
2008.07.29	Su	In	23.8	*Dinophysis ovum*	6.5	7.96	6.4	1.06	5.5	8.94	0.48	1.64	1.3(36.3%)	2.0(18.2%)
2008.07.29	Su	ref	23.8	*Gymnodinium sp.*	13.0	7.97	6.4	0.99	6.3	5.31	0.42	1.50	1.0(26.9%)	7.0(50.0%)
2009.08.21	Su	C2	23.9	*Chaetoceros debilis*	8.0	8.28	6.9	1.19	6.7	3.92	0.13	2.28	4.9(21.5%)	41.0(31.5%)
2004.08.04	Su	In	24.0	*Protoperidinium pellagicum*	6.0	8.25	7.7	1.63	4.1	2.41	0.17	1.39	2.6(30.2%)	14.5(48.0%)
2004.08.04	Su	R2	24.0	*Protoperidinium pellagicum*	8.0	8.17	7.3	1.47	4.5	2.34	0.35	1.74	2.6(48.7%)	3.6(42.9%)
2006.11.16	A	dis	24.0	*Protoperidinium sp.*	1.5	8.07	6.1	0.64	8.0	3.26	0.76	11.43	4.2(54.6%)	4.8(27.8%)
2009.08.21	Su	ref	24.0	*Chaetoceros debilis*	12.0	8.18	6.0	0.91	7.4	4.27	0.16	3.64	6.0(24.3%)	50.0(29.6%)
2003.10.07	A	dis	24.2	*Pseudo-nitzschia smata*	3.5	8.17	8.1	0.86	3.4	5.58	0.45	3.80	42.7(48.8%)	85.5(39.4%)
2008.07.29	Su	L1	24.2	*Thalassiosira rotula*	9.0	7.95	5.5	0.83	6.9	11.64	0.16	3.36	3.0(35.8%)	4.0(26.7%)
2000.07.25	Su	dis	24.6	*Ditylum brightwellii*	8.0	7.54	7.7	1.49	12.0	9.00	0.24	6.11	39.1(37.3%)	38.4(28.3%)
2004.08.04	Su	C1	24.8	*Nitzschia sp.*	11.0	8.20	7.6	1.64	9.5	2.49	0.12	2.08	2.6(45.2%)	11.5(39.1%)
2005.07.12	Su	dis	24.9	*Dinophysis forthii*	2.2	8.08	7.6	1.36	15.2	5.47	0.29	1.51	20.5(27.8%)	115.0(32.7%)
2009.08.21	Su	R2	25.6	*Ditylum brightwellii*	8.0	8.20	6.4	0.99	6.8	4.63	0.19	3.00	8.2(18.5%)	30.0(19.9%)
2005.10.27	A	dis	25.8	*Gymnodinium sp.*	6.0	8.20	7.9	1.01	3.3	3.53	0.21	0.97	1.4(42.6%)	2.8(31.4%)
2009.08.21	Su	R1	26.3	*Guinardia striata*	9.0	8.02	6.5	1.11	6.7	6.77	0.19	3.71	7.7(24.1%)	48.0(28.2%)
2008.07.29	Su	R1	26.4	*Navicula sp.*	9.0	7.93	6.5	1.01	5.1	4.95	0.48	1.71	1.1(37.2%)	2.0(25.0%)
2009.10.21	A	dis	27.4	*Gymnodinium sp.*	9.0	8.01	7.3	1.07	6.8	4.63	0.26	5.78	6.0(49.6%)	12.0(44.4%)
2008.07.29	Su	dis	27.6	*Guinardia flaccida*	6.0	7.92	6.4	0.91	7.0	2.78	0.48	1.71	2.6(30.5%)	3.0(20.0%)
2004.08.04	Su	dis	28.2	*Nitzschia sp.*	7.0	8.12	7.5	1.48	5.6	2.13	0.22	1.62	0.1(41.6%)	1.3(77.8%)
2009.08.21	Su	dis	30.2	*Ceratiumfurca*	6.0	8.17	6.7	1.07	7.1	5.70	0.19	3.00	1.3(11.4%)	11.0(13.1%)
1999.05.11	Sp	C1		*Ceratiumfurca*	5.0	8.08	7.9	0.94	8.0	5.36	0.05	3.35	12.0(21.6%)	87.6(37.8%)
1999.05.11	Sp	C2		*Ditylum brightwellii*	4.2	8.05	8.1	0.89	11.0	6.54	0.04	4.33	39.1(35.1%)	42.8(21.3%)
1999.05.11	Sp	dis		*Ceratiumfusus*	4.5	8.01	7.9	0.99	10.0	6.17	0.04	3.67	27.6(35.6%)	51.8(30.2%)
1999.05.11	Sp	In		*Licmophora abbreviata*	4.5	8.06	8.1	0.87	11.0	6.01	0.04	3.05	18.7(21.7%)	33.6(22.6%)
1999.05.11	Sp	L1		*Ceratium tripos*	4.3	8.02	8.2	0.95	10.0	6.78	0.01	2.87	26.5(25.6%)	31.2(20.0%)
1999.05.11	Sp	L2		*Ceratiumfusus*	4.0	8.04	8.3	0.99	10.0	5.49	0.04	3.23	40.0(31.3%)	34.8(27.1%)
1999.05.11	Sp	R1		*Ceratiumfusus*	3.8	8.07	7.7	1.38	11.0	5.33	0.08	3.84	30.4(30.0%)	54.8(23.2%)
1999.05.11	Sp	R2		*Ceratiumfusus*	4.0	8.11	8.1	1.07	10.0	6.23	0.15	3.35	29.0(37.7%)	48.2(25.6%)
1999.05.11	Sp	ref		*Leptocylindrus danicus*	4.4	8.10	8.4	1.19	11.0	4.85	0.00	3.59	45.1(43.9%)	410.4(73.4%)